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Construction Engineering Research Laboratory

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Center for the Advancement of Sustainability Innovations (CASI)

Tradeoffs for Renewable Energy Projects

Environmental, Planning, and Mission Considerations

Thomas S. Smith, Roch A. Ducey, William J. Stein, and William D. Goran

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Final Report

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Abstract: The U.S. Federal government is pursuing a policy to reduce the rate of fossil fuel consumption, to provide more energy from local, renewable sources, and to effectively use Federal resources to help achieve these goals. Actions supporting these goals are now putting significant pressures on U.S. military bases to provide physical space for wind generators, for solar panel arrays, for bio-energy production, for the transformation of energy from one form into another, and for the entire associated infrastructure related to the operation, transmission, and service of these energy assets. This document explores as-yet unanswered questions related to the potential impacts of these new renewable energy infrastructures on the military installations. Installation Managers need to make informed decisions about the tradeoffs between renewable energy production and ecosystem services, between energy and water availability, and between energy production and current or potential future mission use. This study was undertaken to help inform those decisions.

Executive Summary

The U.S. Federal government is pursuing a policy to reduce the rate of fossil fuel consumption, to provide more energy from local, renewable sources, and to effectively use Federal resources to help achieve these goals. In addition, the Department of Defense (DOD) and its military services have complementary goals to increase the percent of energy used from renewable sources (25 percent by 2025), to reduce fossil fuel consumption and greenhouse gas (GHG) generation, to reduce the rate of fossil fuel usage in forward operations, and to increase energy “independence” or off-grid operations on military bases.

Achieving these goals will help the nation reduce its overall dependence on foreign sources for fossil fuel, diversify its energy sources, revitalize its energy industry, generate new “green” jobs and industries, and reduce the impact of GHGs in the earth’s atmosphere. However, actions supporting these goals are now putting significant pressures on U.S. military bases to provide physical space for (or otherwise contribute to and support) wind generators, solar panel arrays, bio-energy production, the transformation of energy from one form into another, and the entire associated infrastructure for operation, transmission, and service of these energy assets.

Such changes come with a host of as-yet unanswered questions. What are the potential impacts of these new energy infrastructures on the military base missions, their associated ecosystems, their water resources, and other uses on these lands and airspaces? How do we make informed decisions about the tradeoffs between renewable energy production and ecosystem services, between energy and water availability, between energy production and current or potential future mission use?

These questions pose pressing issues for many U.S. military Installation Managers, who need to know what research, policy guidance, lease arrangements, and analyses are needed to help them acquire the appropriate tools to address these challenges such that U.S. installations will welcome efforts to meet their energy needs by generating renewable energy on (and off) installation lands. At the same time, unintended consequences of these new energy assets must be fully understood, and tradeoffs must be accurately and quantitatively expressed to keep installation decisionmakers and managers, the public, and all stakeholders informed about the full costs and benefits of these investments.

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Preface

This study was conducted for the U.S. Army Corps of Engineers, Engineer Research and Development Center (ERDC), Center for the Advancement of Sustainability Innovations (CASI). CASI was established by ERDC, in October 2006, to help enable the U.S. military to proactively respond to current and emerging sustainability challenges. Ecosystem services are one of the CASI technology focus areas.

The work was completed by the Ecological Process Branch (CN-N) of the Installations Division (CN), and the Energy Branch (CF-E) of the Facilities Division (CF), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigators were Thomas Smith, CN-N, and Roch A. Ducey and William J. Stein, CF-E. William D. Goran, of the CERL Technical Director's Office, is Director of Special Projects. Alan Anderson is Chief, CN-N, and Franklin H. Holcomb is Acting Chief, CF-E. Dr. John Bandy is Chief, CEERD-CN and L. Michael Golish is Chief, CEERD-CF. The associated Technical Directors were Martin J. Savoie and Dr. Timothy J. Hayden, CEERD-CV-T. The Director of ERDC-CERL is Dr. Ilker R. Adiguzel.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL Gary E. Johnston, and the Director of ERDC is Dr. James R. Houston.

1 Introduction

Background

Energy, of whatever origin, is absolutely essential and critical to the military mission. Many energy-related issues highlight the need to increase the use of energy derived from renewable sources:

- the worldwide increase in energy needs and demands
- the location of energy sources in foreign countries that are controlled by hostile governments
- environmental pollution and climactic alteration associated with traditional (i.e., fossil fuel) energy source consumption
- increasing costs of energy source extraction and delivery
- declining supplies of these finite resources.

In accordance with the Energy Policy Act of 2005, the Energy Independence and Security Acts of 2007; and Executive Orders 13423 (*Strengthening Federal Environmental, Energy, and Transportation Management*) and 13514 (*Federal Leadership in Environment, Energy and Economic Performance*); the U.S. Government is planning to significantly improve its energy management to save taxpayer dollars, to reduce energy use and emissions that contribute to air pollution and global climate change, and to improve “energy security” for our nation. The expanded use of renewable energy will help achieve all of these purposes.

The Department of Defense (DOD) is the nation’s single largest user of energy. Although the DOD uses only 1 percent of the nation’s total energy use, it uses 78 percent of the Federal government total, of which 12 percent is for electricity. In fiscal year 2006 (FY06), the cost of that energy was $13.6B ($12B in fuel), which equates to 300,000 barrels of oil per day. In more pragmatic, Army-specific terms, a 1 percent decrease in fuel usage in forward operations would require over 6400 fewer soldiers in convoys (U.S. News and World Report 2009). This can be translated into decreased vulnerability, increased safety, and in increased power “at the point of the spear.”

Service Energy Plans

The Army has generally taken the DOD lead in addressing the issues involved with developing and implementing large renewable energy projects. The Air Force's and Navy's efforts to reduce energy consumption have traditionally focused on aircraft and other transportation fuels, which make up the greatest portion of their energy use. By contrast, the Army's overall energy use has been largely (by percentage) related to installations and facilities. Further, the Army Corps of Engineers participates, in some capacity, on all major construction projects of this scale, no matter which DOD service branch is involved. Therefore, this work focuses primarily on the Army's energy strategy – even though the topic of large scale renewable projects relates to all the services.

As part of its obligations under the various Congressional Acts and Executive Orders, the Army has developed a strategy and approach to more effectively manage its energy needs, while at the same time maintaining its strength and obligation to defend and ensure National security. *The U.S. Army Energy Strategy for Installations* (Army Energy Program 2009) calls for the Army to achieve a "net zero energy" status, which will necessarily require additional on-site power and energy production capability. The Army will have to increase energy management and conservation efforts, as well as aggressively pursue on-site renewable energy development on a large, utility scale. The Army's energy strategy and plan includes five major initiatives:

1. Eliminating energy waste in existing facilities
2. Increasing energy efficiency in new construction and renovations
3. Conserving water resources;
4. Improving energy security
5. *Reducing dependence on fossil fuels through increased use of clean, renewable energy that optimizes environmental benefits and sustainability*.

To meet these goals, the Army (and other military services) must make decisions that support all operations regarding energy use, energy availability, and energy production at all levels. These decisions will be made with consideration for current and potential future mission use and requirements, fiscal and other costs for energy infrastructures, and available technologies.

Meeting renewable energy goals

In recent years, the DOD (and/or 3rd-party investors) has developed numerous renewable energy projects directly on DOD lands. However, the percent of renewable energy supplying Defense Department needs is still well below that needed to achieve various goals, e.g., the proposed National standard to require 25 percent renewable energy by 2025. The draft Government Accountability Office (GAO) report* on renewable energy projects in the Department of Defense cites the DOD's failure to meet renewable energy goals.

The Draft Army FY09 Annual Energy Management Report credits the Army with obtaining 2.1 percent of total electricity from renewable energy sources. (The FY09 goal was 3 percent.) Moreover, much of the renewable energy purchases are "credits" from energy suppliers where production of renewable energy is located at a distance from the consuming Defense location. Such credits may help with greenhouse gas reduction goals, but do not improve energy security of Defense facilities, and do not meet the recommendation of the Defense Science Board maintain up to 6 months energy "reserves" for DOD bases. Also, much of this renewable energy was from Renewable Energy Certificates, which will expire at the end of FY10.

The Army's FY10 goal is to achieve 5 percent of total electric use from renewable electric sources. At the current rate of investment, and with present planning efforts and types of funding, it is unlikely that the Army will meet the FY10 goal. One constraint is the long timeline required for the planning, approach, and construction of renewable energy projects. Moreover, the pace at which the Department is able to complete the complex planning for projects with alternative financing also lags behind these goals.

To better make decisions to meet the Services energy goals, Installation Managers must address such issues as the potential impacts these new energy infrastructures will have on the military installation missions, on their habitats, on their water resources, and on other uses on these lands and airspaces. They must consider how they will make informed decisions about the tradeoffs between renewable energy production and ecosystem

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* *Defense Infrastructure: DOD Needs To Take Actions To Address Challenges In Meeting Federal Renewable Energy Goals*, GAO Draft Report, GAO-10-104, GAO Code 351274, 5 November 2009.

services, between energy and water availability, and between producing energy or acquiring produced energy.

These and other issues now stand before military Planners and military Installation Managers. What research, policy guidance, lease arrangements, and analyses are needed to help provide these managers with the appropriate tools to address these challenges, so that U.S. installations will welcome efforts to generate renewable energy on (or obtain from) installation lands, for installation and neighboring community needs. At the same time, managers must ensure that unintended consequences of these new energy assets are fully understood, that the tradeoffs are accurately and quantitatively expressed, and that the Installation Managers, the public, and all stakeholders are well informed about the full costs and benefits of these investments. In a broad perspective, this will include renewable energy assets that are identified as integral to installation energy security and that are located remotely from the installation proper (i.e., islanding concept). In short:

> It's not a question of if, it's a question of when [the Defense Department], and in fact the entire country [will] have to change our energy posture. And if you wait for it to be later, it's pretty painful.
> *Vice Adm. Dennis McGinn, former commander of the Navy 3rd Fleet*
> *Military Officers Tie Energy To National Security*
> http://www.npr.org/templates/story/story.php?storyId=104267992

The Army's sustainability triple bottom line is: *mission*, *environment*, and *community*. In an effort to support the Army's and DOD sustainability, this report addresses environmental, community, and ecological considerations in the development and implementation of renewable energy projects.

Scope

This report is primarily directed toward military Planners and Energy Managers and all others across the military who have responsibilities of ensuring and providing for broadly defined renewable energy availability and security for the U.S. military. Most of the discussions and applications relate to renewable energy considerations for military bases, but also apply to military training, transportation, and the broad spectrum of military contingency operations. For example, solar cell, fieldable biofuel produc-

tion generators, and other renewable technologies may prove practical to supplement electricity or fuel supplies not only for installations, but also for mobile military units, thereby increasing the independence and security of fighting forces.

This report focuses on land-related renewable energy sources and options. Other renewable energy sources and options, such as those associated with hydroelectric power and ocean currents, are not considered.

While specific cases cited in this report are drawn primarily from Army experience, the issues and tradeoffs discussed here are very likely to be broadly applicable to the DOD, and to other Federal agencies and landholders.

2 Renewable Energy

Regardless origin, availability and security of both renewable or non-renewable energy are affected by four segments of the energy chain: (1) resources, (2) generation, (3) transmission and distribution, and (4) the end user.

Renewable energy is generated from natural resources, such as sunlight, wind, geothermal heat, and biomass conversion of many different sources. Ocean currents and tides may also become a source of renewable energy in much the same way the movement of river water through hydroelectric dams is used to generate electricity.

With the possible exception of geothermal sources, all renewable energy technologies are solar in origin. The Earth-Atmosphere system is in general equilibrium such that heat radiation into space equals incoming solar radiation. The resulting level of energy within the Earth-Atmosphere system can roughly be described as the Earth's "climate." The earth's oceans absorb a major fraction of the incoming radiation. Most radiation is absorbed at low latitudes around the equator, and this energy is then dissipated around the globe in the form of winds and ocean currents. Wave motion may play a role in the process of transferring mechanical energy between the atmosphere and the ocean through wind stress. Solar energy is also responsible for the distribution of precipitation that is tapped by hydroelectric projects, and for the growth of plants that create biofuels.

The Army first published a technical note in early 1987 describing its experience with renewable and alternative energy projects, including:

- a biomass wood chip boiler at Fort Stewart, GA from October 1984
- a biomass heat recovery incinerator at Fort Leonard Wood, MO from March 1982
- a fuel cell at Fort Belvoir, VA from March 1985,
- geothermal energy potential listed for 34 Army locations, including Hawthorne Army Depot
- a multisource hybrid project that combined photovoltaics
- wind turbines and a fossil fuel generator sponsored by the U.S. Army Information Systems Command of Fort Huachuca, AZ and tested by

the Solar Energy Research Institute/Wind Energy Research Center in Golden, CO from 1983 to 1986
- a grid connected photovoltaic system at Fort Huachuca, AZ from September 1982 (operational)
- a line focusing parabolic trough solar system for heating, cooling and hot water at Fort Huachuca, AZ from October 1979 (est.)
- a solar pool heating system at Fort Huachuca, AZ from July 1980 (operational)
- a solar domestic hot water system at Fort Huachuca, AZ from July 1981 (operational)
- passive solar housing at Aberdeen Proving Ground, MD from 1986
- two wind turbines at Wilson Lake, KS from December 1983.

Experience from that time has shown that the probability that a renewable energy system will still be working 20 years later depends on the original design and installation and the amount of maintenance and repairs required over the life of the system. To date, lessons learned from these experiences in the Army have not yet been published.

Generated energy typically takes the form of electrical energy. In some cases, heat from geothermal or biomass sources may be the final energy output, or the captured or generated heat may in turn be converted into electricity (Table 1.)

In 1998, it was estimated that approximately 14 per cent of world's primary energy consumption came from renewables (UNDP 2000). In 2006, approximately 18 percent of global final energy consumption came from renewables, of which 13 percent came from traditional biomass such as wood burning. Hydroelectricity was the next largest renewable source (3 percent), followed by solar hot water/heating (1.3 percent). Modern technologies such as geothermal energy, wind power, solar power, and ocean energy together provided 0.8 percent of final energy consumption (REN21 2007).

Climate change concerns emanating from fossil fuel emissions (e.g., coal, oil), high fossil fuel prices (i.e., of oil), and increasing public and government support for curtailing fossil fuel emissions are driving the increases in renewable energy legislation, incentives, and commercialization (UN Environment Programme 2007).

Table 1. Renewable energy, energy products, and applications.

Technology		Energy Product	Application
Wind Energy	Water pumping and battery charging	Movement, power	Small wind machines, widely applied
	Onshore wind turbines	Electricity	Widely applied commercially
	Offshore wind turbines	Electricity	Development and demonstration phase
Solar Energy	Photovoltaic (PV) solar energy conversion	Electricity	Widely applied; further development needed
	Solar thermal electricity	Heat, steam, electricity	Demonstrated; further development needed
	Low-temperature solar energy use	Heat and cold	Solar collectors commercially applied
	Passive solar energy use	Heat, cold, light, ventilation	Demonstrations and applications
	Artificial photosynthesis	H_2 or hydrogen-rich fuels	Fundamental and applied research
	Biofuels	Electricity, fuels	Replacement of fossil fuels
Hydro-Power		Power, electricity	Commercially applied; both small and large-scale applications
Geo-Thermal Energy		Heat, steam, electricity	Commercially applied
Ocean Energy		Power, electricity	Fundamental and applied research

Source: adapted from UNDP, UN Department of Economic and Social Affairs and World Energy Council, World Energy Assessment, Energy and the Challenge of Sustainability, New York, 2000, p. 221

Public support for the combined benefits of decreased fossil fuel use, reduced atmospheric GHG emissions, which may contribute to global climate change, and increased energy independence and energy surety, should not be underestimated or underemphasized.

> The United States Army might be fighting two wars in Iraq and Afghanistan, but that has not stopped the military behemoth from opening a third front against global warming. The progress it has made in that conflict is highlighted in the Army's first annual Sustainability Report released in September. — *GLOBE-Net Staff, as reported in New York Times Blog 01 Dec 08.*

While there are many large-scale renewable energy projects and consequent energy production, renewable technologies are also suited to small off-grid applications, not only for reoccurring and regular Army infrastructure operations (World Energy Assessment 2001), but also in more traditional and classic contingency military actions (AEPI 2007). While the Army currently uses renewable energy systems, most of those systems are located in garrison settings throughout the Continental United States (CONUS) (TREC 2006).

Within the Army, facilities are the largest energy users (Figure 1). These areas (in 1200 active sites), contain thousands of buildings (780 million sq ft in CONUS alone) and other infrastructure (59,000 miles of roads) that are essential to the Army mission. These areas can be physically large (e.g., White Sands Missile Range, NM; 2M acres), and may also be home to thousands of soldiers and support personnel (e.g., over 16K in population) (AEPI 2002). However, military installations, Army or otherwise, are not evenly distributed geographically (Figure 2). While opportunities for the implementation of renewable energy projects abound, the distribution of renewable energy sources is unevenly distributed (Figures 3, 4, 5, and 6).

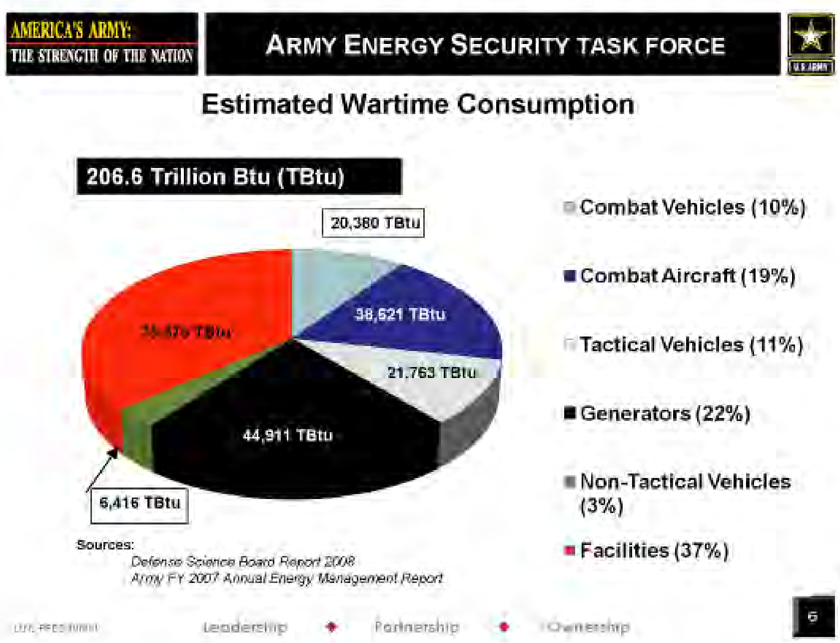

Figure 1. Estimated Army energy consumption.

Figure 2. Military installations in the continental United States.

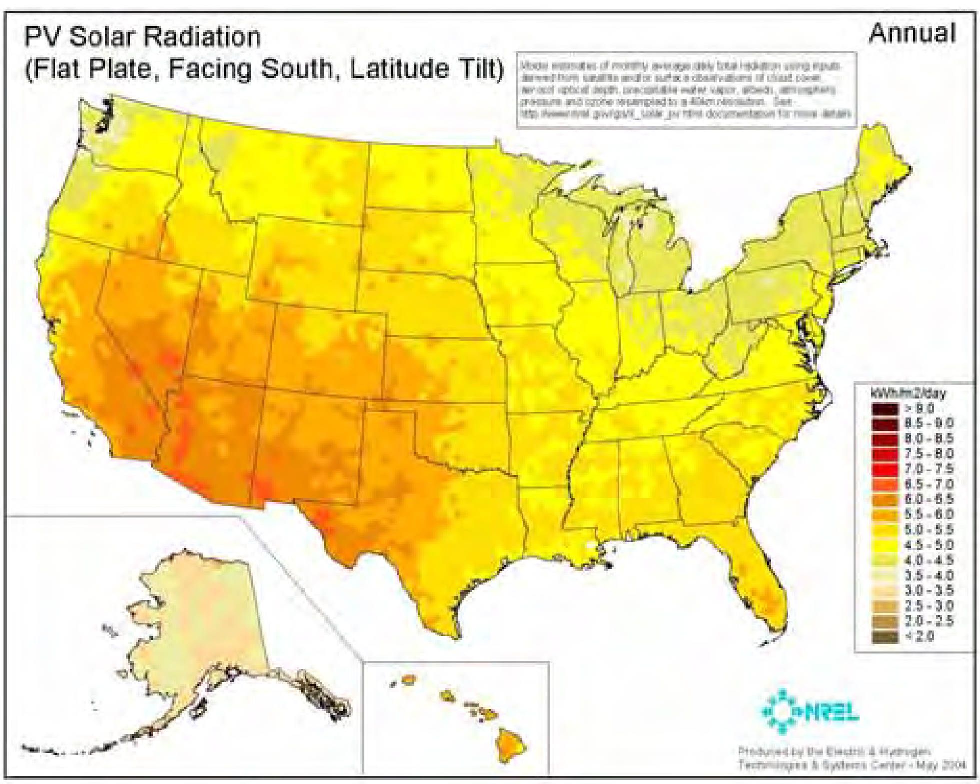

Figure 3. Relative solar radiation and associated solar radiation energy potential.

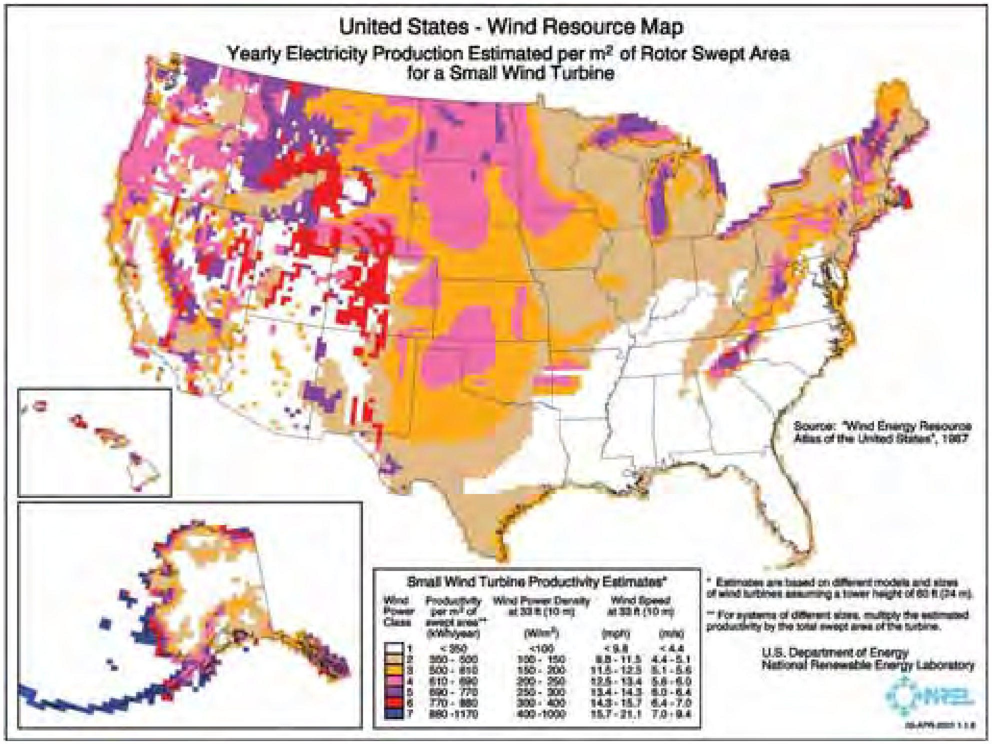

Figure 4. Map of wind resources and estimated potential electric energy production from small turbine applications.

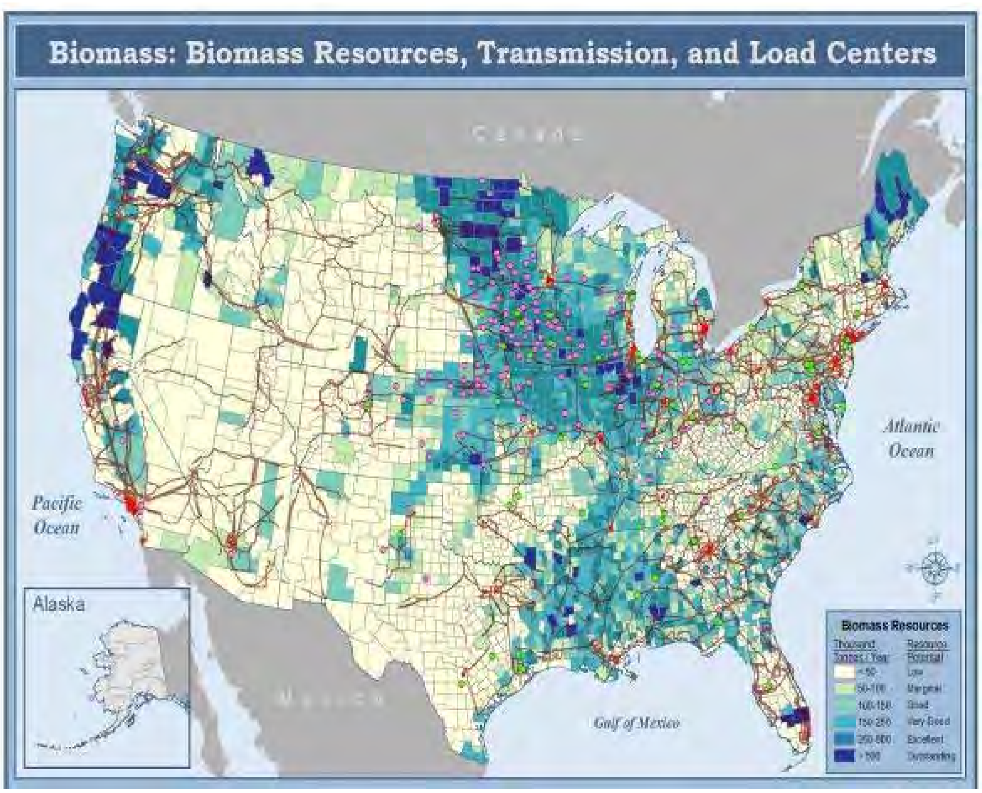

Figure 5. Potential biomass resource areas and transmissions centers and paths.

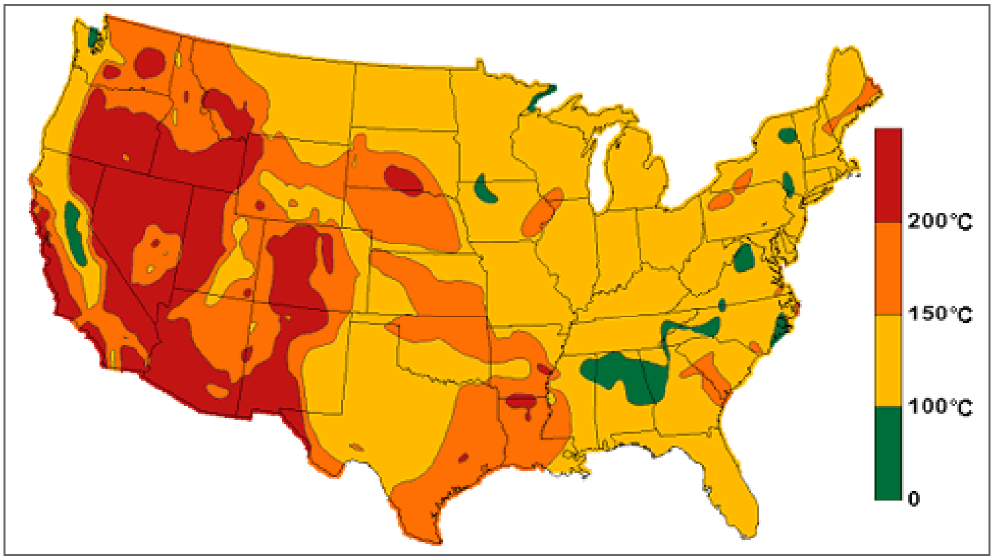

Figure 6. U.S. generalized geothermic resource potential.

Solar energy

Solar energy is ubiquitous and universally (if not evenly) distributed (Figure 7). Two attractive features and advantages of solar power is that the energy itself does not cost anything and the solar panels employed to convert solar energy into heat or electricity give off no pollution. Solar energy can also be used to desalinate water, a feature that may become more important as concern over water supply and quality increases. However, the high initial cost of solar collection technology must be weighed in part against costs over an effective life span. Additionally, electricity resulting from solar sources can only be produced during the day. A solar-based electrical generation system will require either electrical storage or a supplemental electrical generating system. Further, air pollution and overcast or cloudy conditions in some areas can limit the number of effective days of solar radiation, or reduce radiation efficiency.

To date, the only utility-scale solar energy electric power generating systems installed at DOD installations have been photovoltaic (PV) power stations, the largest of which in the Western Hemisphere was installed at Nellis Air Force Base (AFB), NV, near Las Vegas (Figure 8).

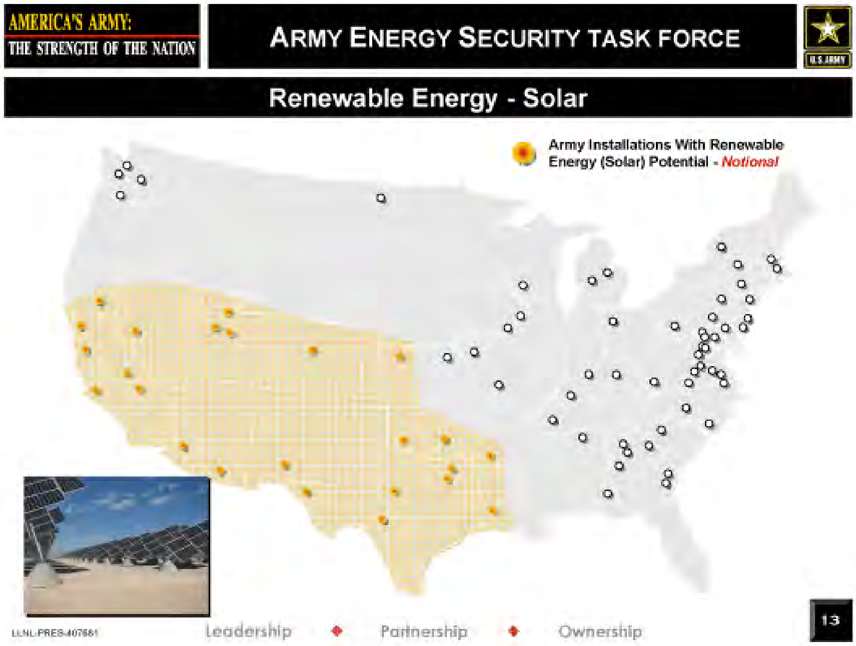

Figure 7. Generalized relationship of regional high solar radiation and Army installations.

Figure 8. Solar energy station at Nellis Air Force Base, NV.

The 14-megawatt power station occupies over 140 acres of ground and was located on an old industrial site. This follows a general rule-of-thumb to conservatively allow an acre of ground for each 100-kW of installed PV array. Some site remediation was performed as part of installing the PV station. This increased the cost of the project, but could be considered as resulting in an improved environmental condition at the site.

A 2-MW PV power station was also installed at Fort Carson, CO (Figure 9). This system covers nearly 20 acres of an old landfill site, so, like the Nellis AFB project, environmental concerns were minimal. Both of these systems were installed, and are owned and operated, by private developers and the power is sold to the DOD installations. Though, from the start, both of these projects were beneficial from an environmental perspective, future proposed solar power stations may require much more scrutiny. For example, the work to locate a 500 megawatt (MW) solar thermal electric power station at the National Training Center—Fort Irwin, CA, began in the summer of 2009. The proposed solar electric generating system (SEGS) would be similar to the systems at nearby Daggett and Kramer Junction, CA, that have been operational for many years (Figure 10). Similar to the PV projects at Nellis AFB and Fort Carson, the system(s) would be installed, owned, and operated by a third-party developer, under a long-term (20-years+), enhanced use lease (EUL) contract.

Figure 9. Two-MWp PV power system at Fort Carson, CO.


Figure 10. SEGS at Daggett and Kramer Junction, CA.

During normal operating conditions, the solar plant would simply provide power to the regional grid that supports Fort Irwin. In the event of an extended power outage, the system could be configured to “island” from the grid and continue to provide power to Fort Irwin, thereby enhancing energy security. Fort Irwin’s typical peak load is on the order of only ~30 MW, but excess capacity from the solar power plant could be stored via a variety of energy storage technologies, including hydrogen production for use in a fuel cell when the solar plant is not producing power.

The Fort Irwin project would cover many hundreds of acres; the environmental impact on a previously undeveloped area of the Mojave Desert would need to be accurately addressed. Similarly, because of multiple governmental jurisdictions and multiple environmental resource issues, this type of project would require substantial coordinated planning and environmental analysis. It is likely that future DOD utility-scale solar energy projects will be more similar to this Fort Irwin example than to the relatively simple cases at Fort Carson and Nellis AFB.

Wind energy

Although the use of wind power no doubt dates even further back in antiquity, the earliest known use of wind power is by the Egyptians some 5000 years ago, who used it to sail boats on the Nile. Around 2000 BC, the first windmill was built in Babylonia (present day Iraq). In present day Afghanistan, large windmills (as high as 30 ft, with 16-ft long blades) were in use by the 10th century BC. In 2005, the United States was the fastest growing

wind energy producer in the world; today, it is China (Alternative Energy Sources 2009). Since wind generation and movement ultimately originates in the atmospheric heating effects of solar radiation, the potential for wind energy, like solar energy, is attractive because it is derived from a ubiquitous, widespread, abundant source (Figures 4 [p 11] and 11). Costs depend on the scale of the electrical generation wind turbines and available wind. Off-shore siting of wind turbines or “windfarms” has some attraction. However, off-shore windfarms are more expensive to maintain than land-based plants as they can only be accessed by ship or air.

While wind-generated energy is attractive from standpoints of supply and cost, it does have some disadvantages. In addition to the fact that the wind-powered energy generation does not yield a reliable, constant energy flow, wind turbines are also not aesthetically pleasing in usually open natural areas where they are commonly employed. Additionally, there are significant concerns and issues with bat and migratory bird mortality, and the impact of large windmill structures on radar systems.

Presently, there are no large scale windfarms on DOD lands. There are a few Air Force and Naval facilities that use a relatively small number of wind turbines to augment an existing diesel generator grid, which helps to reduce fuel consumption. In 1996, for example, the Air Force installed four 250-kW turbines at their missile tracking facilities on Ascension Island, between Africa and South America in the Atlantic Ocean (Figure 12). The project was so successful in reducing diesel fuel consumption that the Air Force invested in additional wind turbines and a 2-MW PV power system.

More recently, recommendations from the *DoD Renewable Energy Assessment: Final Report* (DOD 2005) Renewable Energy Resource Assessment at Department of Defense Installations,” called for a short-term strategy to increase renewable energy use at DOD installations, by seeking opportunities to purchase “green” power, typically from existing windfarms located near DOD installations. Unfortunately, this strategy does not completely accomplish the long-term goal of enhancing energy security by having on-site renewable energy generating capacity. The 2005 report did, however, identify an area near the shared border between Fort Bliss, TX, and White Sands Missile Range, NM as having sufficient wind resource to support as much as a 300-MW windfarm.

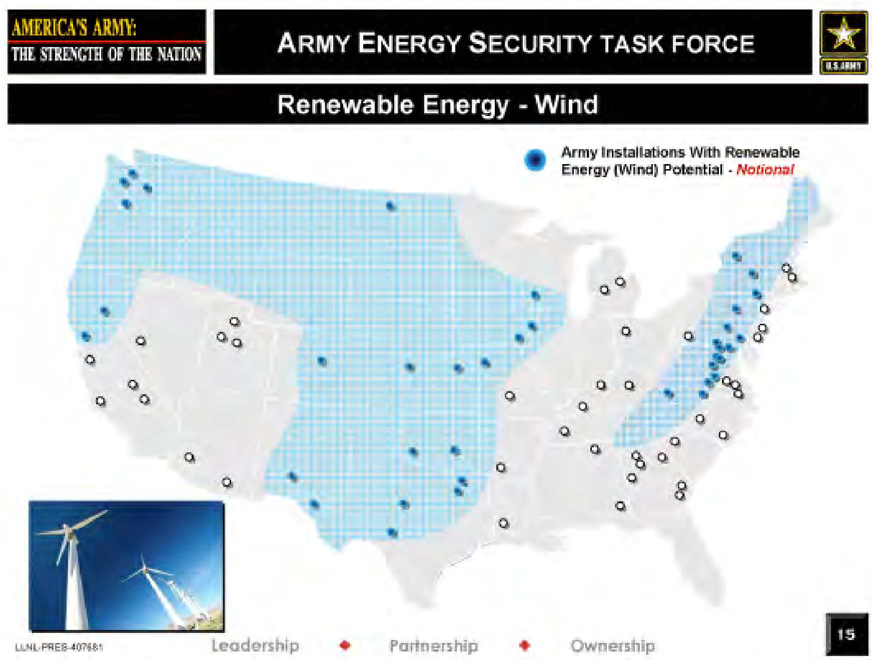

Figure 11. Generalized relationship of regional wind energy potential and Army installations.

Figure 12. Air Force turbines at missile tracking facilities on Ascension Island.

This resource is being considered for development, as is being done for the Fort Irwin solar power plant, through a long-term EUL with a 3rd party wind developer. The environmental issues for such a wind project in Texas/New Mexico will need to be pursued with the same rigor as the California solar project.

In September 2009 the Army Assistant Chief of Staff for Installation Management (ACSIM) funded a study with the U.S. Army Electronic Proving Ground to determine the interaction of commercial scale wind turbines on Army electronics and radars. That 18-month study will collect data on the interactions and report on results, mitigation measures, and planning factors for the placement of wind turbines on or near Army installations.

Biomass conversion

Biomass-derived energy can be a part of the equation to reduce foreign oil dependency, but biomass-derived energy sources can also be associated with significant environmental and ecosystem impacts. Biomass is solar in origin in that plants use photosynthesis to convert solar energy into plant material and carbon dioxide. These plant or plant-derived materials (e.g., wood, paper, manure, sewage and waste, algae and aquatic plants, and agricultural crops) can be used to produce usable forms of energy.

Biomass energy can be used directly or indirectly. Burning is a common example of direct use by combustion. Gas derived from thermal or biological processes can be used directly as a heating source or to drive turbines to generate electricity. Biomass can be used indirectly by conversion into other forms of fuel, e.g., ethanol from crops such as sugar cane and forest products such as wood chips, and methane from sewage and land-fills.

The use of biomass energy does have disadvantages. Unlike solar, wind, geothermal, or ocean energy, GHG are produced by burning or fuel combustion. Further, large scale crop production uses large amounts of land (Figure 5, p 11) and water, and also requires large energy inputs (i.e., fuel). Nonetheless, biomass energy has a place as one component of a renewable energy “portfolio.” Biomass energy does have a significant advantage in that the fuel can be stored so that electrical or thermal energy may be generated on demand. This is significant in terms of energy security; it makes biomass energy an ideal complement for other renewable energy sources.

The only large-scale biomass energy system within the DOD is a central heat plant at Fort Stewart, GA, which is fired with wood waste from nearby lumbering operations. This system has operated successfully for nearly 20 years and has provided Fort Stewart with substantially lower energy cost. However, the lumber industry now uses increasingly more of what was once considered "waste" to produce wood-based building materials so a sustainable, low-cost fuel stream is no longer as certain as it once was when the plant was originally installed.

It is not likely that DOD installations will set aside large sections of land for producing "energy crops" (Figure 13) that can then be used to produce ethanol or other renewable alternative fuels. However, some installations have been approached by private firms proposing to grow "biofuel" crops on installation grounds. In such cases, the full GHG and ecosystem consequences of these proposed actions need to be examined by the Installation Managers. The "costs" could easily exceed the benefits – given that there are considerable inputs to plant, nurture, and harvest biomass (wood or crops); there are significant habitat, nutrient and soil loss "costs" for such operations; and water is often a significant input.

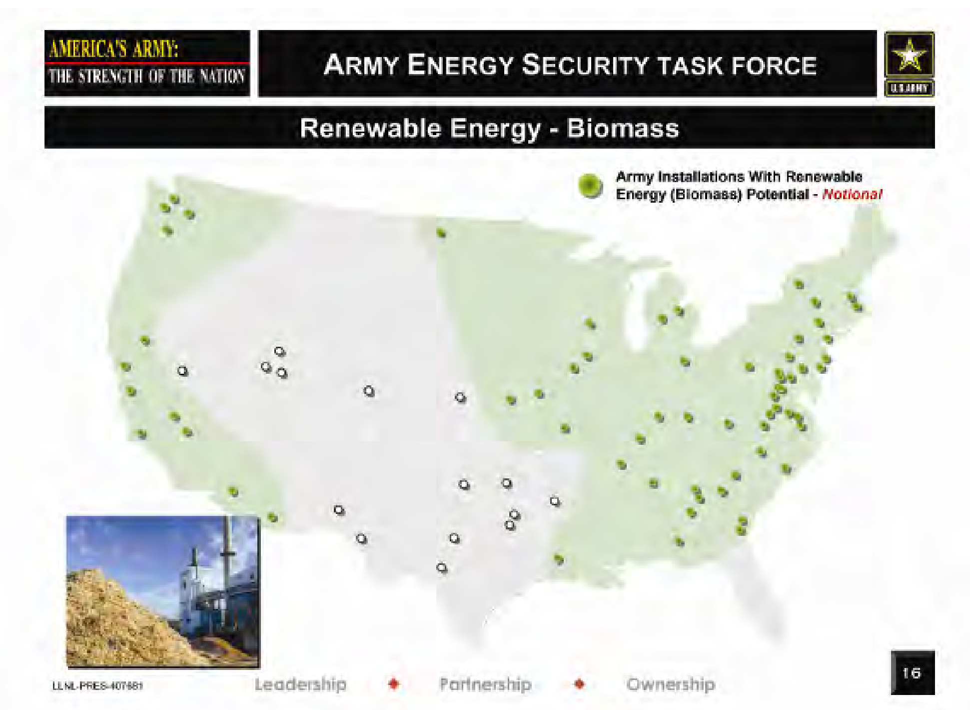

Figure 13. Generalized relationship of regional biomass production potential and Army installations.

However, it is likely that the biomass concept of waste-to-energy will be added to the portfolio of renewable energy resources, as it also helps installations to use waste streams as resources rather than to simply accept them as a costly expense of installation operations. A number of different technologies can convert biomass resource streams such as municipal solid waste (MSW), anaerobic digester gas (ADG) from wastewater treatment plants, and landfill gas into useful energy.

For example, MSW can be direct fired in a heat recovery incinerator (HRI) and the heat energy used to directly serve a heat load or to drive a steam turbine to generate electricity. The environmental issues that need to be addressed in implementing these waste-to-energy technologies can be minimal when compared to other biomass energy concepts.

Geothermal

Geothermal energy is defined as heat from the Earth. Geothermal heat is a powerful energy source. Heat dating from the origin of the planet continues to radiate from the earth's core into the intermediate mantle zone. Where the mantle is close to the earth's surface or crust, geothermal energy shows itself in the form of volcanoes, geysers, hot pools, and mud pools. Although areas like hot springs are most obvious and are often the first places geothermal resources are used, the heat of the earth is available everywhere, and its use in a broader range of applications is being developed. The heat continuously flowing from the Earth's interior, primarily by conduction, is estimated to be equivalent to 42 million megawatts of power, and is expected to remain so for billions of years, ensuring an inexhaustible energy supply (Figure 6) (Geothermal Energy Association 2009).

Geothermal heat pump technology is theoretically applicable to many situations and areas around the country. However, current costs are prohibitively high for large scale, central heat plant applications. This is also true for a closed-cycle vapor turbine technology, which can use a low-temperature geothermal resource to drive the turbine and generate electricity. But these approaches are only practical on a relatively small, distributed generation scale (100-kW, or less).

Unlike the intermittent nature of solar and wind renewable energy systems, geothermal energy can be used for continuous electric power production, for commercial, industrial, and residential direct heating purposes, and for efficient home heating and cooling through geothermal heat pumps. To use this heat energy requires literal hot spot locations within the earth's crust. These are common around volcanoes and fault lines, but for obvious reasons these are not necessarily areas where one would want to build a geothermal energy plant. Thus, given current technology, suitable locations for geothermal energy applications are somewhat limited.

While some potential for geothermic energy use on DOD installations exists (Figure 14), the only large scale DOD geothermal electric power plant that has been built to date is the 270-MW facility located at the Naval Air Weapons Station (NAWS), China Lake, CA (Figure 15). The high temperature geothermal resource is brought up from wells that are over 10,000 ft deep. The superheated steam drives turbines that produce the electricity and the resulting hot water is then sent back down to the source through reinjection wells. Compared to similar scale solar and wind power plants, geothermal power plants have a much smaller "footprint." However, there is still a comprehensive list of environmental issues that must be addressed with the same rigor as the other renewable energy technologies.

The 2005 DOD renewable energy assessment report identified Hawthorne Army Depot in Nevada as having the same potential for geothermal development as the China Lake plant. Some preliminary studies have been conducted and a notice for opportunity to lease (NOL) will be released sometime in late FY09 or early FY10. The NOL process is the same approach that was used in soliciting contractors for the Fort Irwin solar power plant EUL project, mentioned earlier.

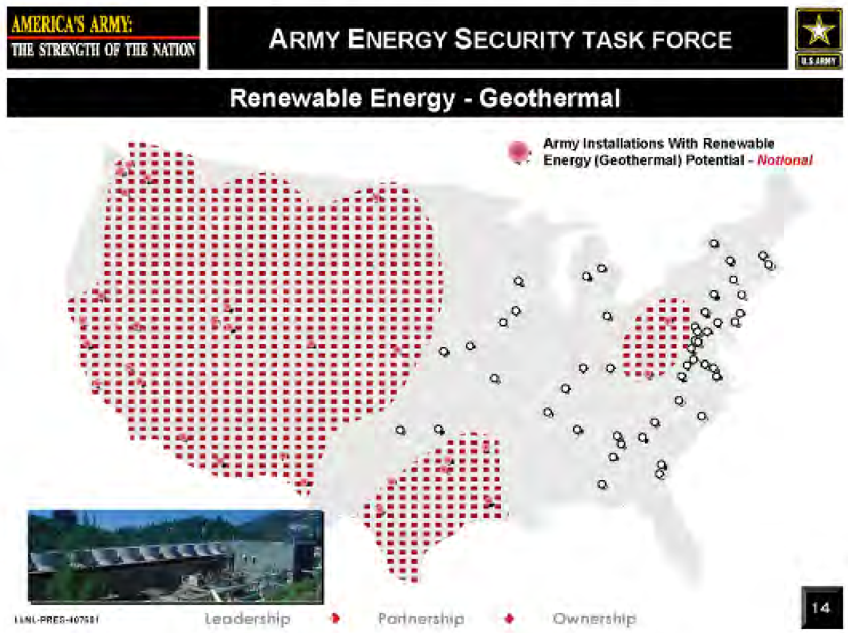

Figure 14. Generalized relationship of geothermal energy production potential and Army installations.

Figure 15. DOD 270-MW geothermal electric power plant at Naval Air Weapons Station, China Lake, CA.

3 Mechanisms and Approaches

The purpose of this report is to provide an overview of environmental and (other considerations) relative to the development and implementation of renewable energy approaches, efforts, programs, and projects on military installations. All Federal programs are based on laws and regulations passed by the Congress. Within the general authorities granted to all Federal Departments and agencies, DOD may become involved in renewable energy acquisition and development efforts. For example, military organizations may enter into agreements to lease land for the production of renewable energy, and to purchase renewable energy. Other related authorities relate more specifically to renewable energy development, and more generally to land and natural resources management.

Authorities Related To Renewable Energy Utilization

Sikes Act

Renewable energy is a natural resource. The Sikes Act (16 USC 670 et seq.) authorizes and requires the DOD to establish a program to provide access to the natural resource assets (forest products, grazing land, crop production, etc.) on military bases, and to provide for the conservation and multipurpose use of natural resources on military installations. The Act recognizes the importance of the military mission and provides for no net loss in the capability of military installations to support the mission. In the context of this Congressional directive and existing structure, Integrated Natural Resources Management Plans could be the appropriate vehicle to identify renewable energy management opportunities, efforts, and plans. The plans are developed in coordination with stakeholders such as regulators and representatives of the communities that might seek access to these resources.

Military land withdrawal

In concert with the Sikes Act, various withdrawals or transfers of Federal lands from other Federal Departments to DOD are possible. Public lands may be withdrawn and reserved for military training and testing in support of our National defense requirements. Such withdrawals and reserva-

tions are authorized by Act of Congress (for withdrawals of over 5000 acres) or by order of the Secretary of the Federal agency involved Interior or (for withdrawals of less than 5000 acres). Congressional authorizations are generally referred to as Military Lands Withdrawal Acts and most commonly involve the U.S. Department of Agriculture (e.g., Forest Service lands) and U.S. Department of Interior (e.g., Bureau of Land Management lands).

Recent withdrawals have involved the transfer of 1.6 million acres in Arizona* (Military Land Withdrawal Act of 1999, Title XXX of P.L. 106-65) and 110,000 acres in California (Fort Irwin Military Land Withdrawal Act of 2001, Title XXIX of P.L. 107-107). Although the military has primary jurisdiction over use and management of withdrawn lands under provisions of the Sikes Act, the Department of the Interior (DOI) must participate in the development of an Integrated Natural Resources Management Plan, conduct a periodic land use review, and provide a public report. A withdrawal review is required, in part, by the Federal Land Policy and Management Act (United States Code Title 43, Chapter 34). This process enables the DOI (in the case of DOI lands) to determine if a withdrawal is still being used for the purpose for which it was established. If the military fails to adequately manage the natural and cultural resources of those lands, the transferor Department may assume management responsibility.

This reference to militarily withdrawn lands is relevant here because, in some instances, renewable energy development projects may be placed on or may use withdrawn lands. In these instances, close coordination with the transferor Department and the DOI is necessary to ensure compliance with the provisions of the Sikes Act.

Military lands and Federal, State, and local coordination and permitting

Other authorities (including Title 10 Armed Forces, in particular 10 USC 2667 and 2668) allow for the sale or lease of generated renewable energy. However, the Authorities (Federal, state, or local) that either have or establish jurisdiction over the approval of renewable energy systems can help make the location of such facilities complex and lengthy.

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* The Act also extended previous withdrawals, in Alaska (Fort Greely and the Yukon Range at Fort Wainwright), in Nevada (Nellis Air Force Range and the Naval Air Station Fallon Ranges), and in New Mexico (McGregor Range, which is associated with Fort Bliss).

Under Federal law, energy projects on Federal lands must provide environmental documentation. They must also comply with the rules of various Federal agencies governing the location of electrical transmission or thermal pipeline access, and gain approval of land use if the land is withdrawn. Such projects, must also comply with any future Federal laws with jurisdiction.

State laws governing the location of large-scale renewable energy projects vary in the type and complexity of their processes. Each state has a utilities commission or other authority that oversees an approval process for larger scale generating and transmission projects that may take years to successfully complete.

Local coordination with counties, cities and towns can also be lengthy. For example, some state and local laws do not allow waste-to-energy plants that use an incineration or mass burn type technology, no matter how clean the emissions are from current technologies.

Direct funding for renewable energy projects

For many years, renewable energy projects (usually relatively small technology demonstration projects) have been developed and implemented with Energy Conservation Investment Program (ECIP) military construction appropriated funds. The limited amount of ECIP funds, typically ~$100M/year for all DOD service branches, restricts the size and number of these projects. In addition, renewable energy projects compete with other types of energy conservation projects that, historically, have generally more favorable economic feasibility analyses. For the most part, these restrictions eliminate any true utility-scale renewable energy projects from being proposed. Nevertheless, in the mid-1990s, ECIP funded a 450-kW-peak, grid-connected photovoltaic power system, installed at Yuma Proving Ground, AZ—the largest solar project within the DOD at the time.

Alternative financing authorities for renewable energy projects

A number of financing authorities have been used to fund renewable energy projects at DOD facilities. For the most part, these relatively small systems do not fit the definition of “large-” or “utility-scale” projects, which, by definition, must generate 10-MW or more of power output, and which typically require a hundred acres or more of land. Currently, renew-

able energy projects of this size (minimum 10-MW) will cost about $100M for solar and about $30M for wind projects. (These two renewable energy technologies have the broadest applicability across DOD for large-scale, grid-connected systems.) It appears unlikely that appropriated funds will become available for DOD projects of this scale. Development and implementation of large-scale renewable energy projects on DOD lands will most likely require private sector investment.

Energy Savings Performance Contract (ESPC)

These types of projects are implemented though third-party investment. The contractor installs and, if required, operates the energy saving equipment. The contractor's investment is recovered through the energy cost savings generated by the renewable energy system. Payback periods of up to 25 years are allowed under ESPC, but contractors typically prefer to keep their investment tied up no more than 10 years (usually less time than that). Renewable energy projects almost always have a longer payback than 10 years, so they are sometimes "bundled" with other quicker payback projects, like lighting retrofits. In that way, the overall packaged project meets the ESPC contractor's investment criteria. Because of this lack of interest in a very substantial long-term investment, no large-scale renewable energy projects have ever been proposed under ESPC.

Utility Energy Services Contract (UESC)

This funding mechanism is very similar to an ESPC, except that the third-party investor is the local utility. The payback period is loosely tied to a 10-year "utility service" term limit in Federal Acquisition (FAR) 41. This constraint obviates its use for renewable energy projects other than smaller applications that might show a quick return on investment. For example, Southern California Edison used an UESC to install a number of small photovoltaic power systems for off-grid or difficult-to-access facilities at Fort Irwin, CA, where extending the utility line was not cost-effective.

Power Purchase Agreement (PPA)

On-site PPA projects are developed by third-party investors, with long-term contracts to sell output from the renewable energy systems to the government at a specified price. Examples of this financing mechanisms are the Nellis AFB and Fort Carson solar projects. To more expeditiously

meet renewable energy goals, DOD installations have also used the PPA approach for purchasing “green power” from existing off-site, large-scale renewable energy sources (like windfarms).

Renewable Energy Certificates (RECs)

RECs are the purchase of the renewable energy attribute of the electricity generated from a renewable energy source. While purchase of the RECs can be used to meet the mandated renewable energy goals, they do not necessarily add to energy security or even ensure that the renewable energy is from a system on or near the installation. The price of the RECs are determined by local market conditions. While the RECs were set up to be an economic incentive to install more electrical producing renewable energy projects, they can hinder the installation of these systems on DOD lands. For a military installation to get credit for the renewable energy (electrical) produced from a new system installed on its’ property, it would have to come up with the extra dollars to buy the RECs.

Public Private Venture (PPV)

PPV is something of a misnomer, but it is the term the Navy uses to describe the DOD Geothermal Program process. The Navy Geothermal Office implements the program under provisions of 10 USC 2917, “Development of geothermal energy on military lands.” Land is leased for energy projects subject to payment of royalties on commercial sales, into a Navy fund reserved for energy projects. This approach is virtually a one-of-a-kind financing option that was established through an Act of Congress in the late 1980s to allow the 30-year PPV contract that ultimately installed the 270-MW geothermal power plant at the Naval Air Weapons Station, China Lake, CA. This financing authority is being considered (only the second time since it was first established) to install a similar geothermal power plant at Hawthorne Army Depot in Nevada, which basically sits on the same geothermal resource as NAWS China Lake.

Enhanced Use Lease (EUL)

The EUL option was created to address the disposition of facilities and assets at DOD installations being closed, realigned, or otherwise underutilized. This approach includes land leased for “commercial” power projects in exchange for “in-kind” lease payments. In execution, the EUL is similar

to the Navy PPV, but can include all large-scale, long-term renewable energy contracts, not just geothermal projects. The EUL may be the most appropriate option for most DOD large-scale renewable energy projects.

EUL details

Started in 2001, the Army EUL program has progressed from an ambitious concept to a successful reality. The EUL program is managed by the U.S. Army Corps of Engineers, Baltimore District. Through a competitive process, it engages private sector entities to acquire and leverage value from under-utilized, non-excess real estate assets on Army and other DOD installations. This mirrors a private sector transaction; the EUL's value proposition is competitive on cost and speed of execution. The EUL program leverages the power of private capital and expertise to fund installation maintenance and operation costs in exchange for long-term leases of Army land through the statutory authority of Title 10 USC, Section 2667.

Through the authority of Title 10 USC § 2667, DOD has the ability and incentive to obtain a broad range of financial and in-kind considerations for leasing opportunities. Comparatively recent changes to Section 2667 expand the purposes for which lease proceeds may be used, and augment the types of in-kind consideration that may be accepted for leases. These changes maximize the utility and value of installation real property and provide additional tools for managing the installation's assets to achieve business efficiencies. Specifically, installations can, among other things:

1. Enter into long-term leases, providing greater flexibility for facility use and reuse, and
2. Receive cash or in-kind consideration for income on leased property, which can be used for:
   a. Alteration, repair, improvement of property or facilities
   b. Construction or acquisition of new facilities
   c. Lease of facilities
   d. Payment of utility services
   e. Real Property Maintenance Services.

Enhanced Use Leasing offers installation commanders and DOD numerous benefits:

- It enhances mission performance through cooperative efforts with private developers.

- It improves utilization of property.
- It reduces base operating costs through improved business practices.
- It stimulates the local job market.
- It fosters cooperation between the military services and private sector.
- It introduces valuable Federal property into the local market.

The Deputy Secretary of the Army for Installations and Housing (DASA(I&H)), by a delegation from the Secretary of the Army, must approve the leasing of any real or personal property for more than 5 years. The property must not be considered "excess" property to qualify. Leases may be entered into if the DASA(I&H) considers it advantageous to the Army and the United States, and upon such terms as he considers will promote the National defense or be in the public interest. Potential uses for Enhanced Use Leasing include:

- Wind
- Solar
- Geothermal
- Bio-mass
- Waste to Energy
- Coal Gasification
- Cogeneration
- Central Utility Plants Vehicle Test Tracks
- Wetlands
- Other Energy Production.

Potential EUL issues:

A number of major issues must be addressed in an EUL contract so that a successful large-scale renewable energy project can be initiated. These considerations include, but are not limited to:

- whether the EUL Option is the Right Authority for Financing Large-Scale Renewable Energy Projects on DOD Lands
- whether revenue distributions comply with the Sikes Act provisions
- whether there is a scale threshold for project economic feasibility and private sector interest (e.g., 10-MW, 100-MW, etc.)
- identification of DOD's liabilities in the event of a failed venture
- whether the project provides for technology evolution
- whether environmental issues are addressed, not only at the DOD site, but also in the areas associated with the distribution of the power to the ultimate end-users
- whether land ownership (e.g., withdrawn lands or not) issues are resolved.

EUL example: The Fort Irwin solar power plant project

In the summer of 2009, the U.S. Army Corps of Engineers (Baltimore District, Enhanced Use Leasing Program Office) announced its selection of Irwin Energy Security Partners LLC, a team comprising Clark Enterprises of Bethesda, MD affiliates,* and Acciona Solar Power of Henderson, NV, to develop, construct, and manage the largest solar power project proposed to date within the DOD at Fort Irwin, CA.

The Fort Irwin Solar Energy EUL will entail a flexible, phased, multi-technology approach to delivering up to 1000 megawatts (MW) of power generation while advancing the transformation of Fort Irwin's overall energy security. The Clark-Acciona proposal features concentrated solar thermal and photovoltaic technology capabilities development at an industrial scale.

The proposed first phase will produce more than 500 MW of renewable energy and 1250 gigaWatt hours (GWh) of solar power electricity generated per year at Fort Irwin facilities by 2022. The Clark-Acciona proposal calls for a phased implementation that holistically considers site characteristics, constraints, available resources, current and future technologies, cost, access to transmission lines, and length of approval and connection processes at each stage of construction.

The Fort Irwin Solar Energy EUL was identified as a pilot project by the Secretary of the Army in October 2008 at the launching of the Senior Energy Council, which was tasked to coordinate and promote energy security and policy for the Army. This includes both measures to conserve and use energy wisely, and to promote the production of alternate sources of energy from the Army's substantial land holdings across the United States.

* Clark Realty Capital, Clark Energy Group, Clark Construction Group, and Clark Builders Group.

4 Environmental and Mission Considerations

The development and implementation of renewable energy opportunities, efforts, and projects can present significant challenges in ecosystem management and ecosystem tradeoffs. This is true whether the military services are a proponent, a user, or consumer (or some combination of these roles). These challenges can include the selection of optimal sites for new renewable energy facilities and infrastructure, access to and impacts on selected locations, and the system consequences of new facilities and infrastructure on sensitive environments. The associated infrastructure to support those developments, including conversion, transmission, storage, and transportation, can also result in changes not only in environmental conditions, but also in the distribution and demographics of human populations.

The following sections discuss environmental and ecologic attributes and decision factors for consideration in renewable energy projects. The discussion of each attribute or factor is not intended to be encyclopedic, all inclusive, or complete. Rather, the intent is to illustrate and call attention to “system” considerations to be addressed when considering renewable energy projects. By fully recognizing and analyzing ecosystem attributes, decisionmakers will be able to more effectively balance the ecosystem, environmental, and other tradeoffs necessary to effect renewable energy projects that achieve Army renewable energy goals, comply with Congressional mandates, and maintain National energy, military, and environmental security.

These factors do not stand alone; they are interrelated. An alteration of one can result in significant changes or effects on others. For example, in the real world environment, soils, water resources, and land use are linked together so they contribute to and are influenced by the other. These in turn influence the native species composition of an area and help determine human population distribution. Thus, these attributes must be examined in the context not only of the environment, but also in the context of the nature and extent of the renewable energy effort proposed.

Geology, soils, seismic activity

In renewable energy projects, as in any construction or facility development, substrate is important. Any engineering and other site plan for renewable energy developments must consider substrate, as it must consider (and incorporate appropriate mitigation measures for) the likelihood and influences of water and wind erosion. For obvious reasons, other than perhaps for geothermal energy applications, facilities should not be built on fault lines or in earthquake zones where they would be at high risk for earthquake damage.

The importance of geologic conditions to the siting of geothermal energy facilities is also obvious. In a sense, this is also an impediment in that one of the biggest disadvantages of geothermal energy is the low number of suitable locations. An ideal location would have suitable hot rock sources at a depth that allows for easy drilling. The type of rock above the hot rocks must also be easy enough to drill through. If groundwater is not present, then large surface water supplies may required. This in turn may result in other ecological concerns, and may place other ecological and environmental constraints on development. On the other hand, low level geothermal energy sources, such as derived by heat pumps, are widely available, and are not so constrained by these siting considerations.

The construction of large solar and wind renewable energy arrays can result in significant surface soil disruption and subsequent erosion and sedimentation, but best management practices can limit the surface soil disturbance and avoid soil loss. Use of military lands for the production of biomass for energy purposes is subject to all the environmental concerns associated with crop and forest management.

Climate

Climate and climatology can play a major role in siting considerations for renewable energy development. As illustrated previously, there are regional differences in renewable energy production potential. Larger scale solar energy development in the Pacific northwest, where cloud cover is common, would not be as practical as in the southwest where cloudless days are the norm. A similar situation exists with wind energy potential. Open areas, which are most often associated with non-military or private land ownership, may not necessarily be located close to military installa-

tions. Thus, the realities of climactic influence on renewable energy “location” may well require consideration of transmission facilities to transport that energy to military locations.

Biology

Renewable energy development is not environmentally neutral in relation to aquatic and terrestrial ecosystem biology. Direct impacts from construction and placement of renewable energy facilities can include mortality (Figure 16), and habitat modification and destruction. Where habitats exist close to renewable energy (and related) facilities and development, indirect effects can include habitat fragmentation and habitat avoidance. While best known wind energy concerns are for birds and bats, impacts and effects on larger animals such as deer, small mammals, and other life forms such as reptiles (e.g., the desert tortoise), are less well understood. Such effects may be local or regional. For example, one must consider whether the materials in solar arrays might attract wildlife, which may damage the equipment, resulting in potential negative health impacts on the wildlife.

Figure 16. Example of a direct biological effect of renewable energy development.

Renewable energy facility development in bird (including those offshore), and terrestrial and marine mammal migration routes may be problematic, in that they may impact species at population levels (Figures 17 and 18). Also, any renewable energy development project with a Federal nexus (which, for all practical purposes, is any renewable energy development that the military services might have interest in) will require consideration of threatened and endangered, and at-risk species. Given the high social interest in threatened and endangered and other protected species, renewable energy developments must allow for those species.

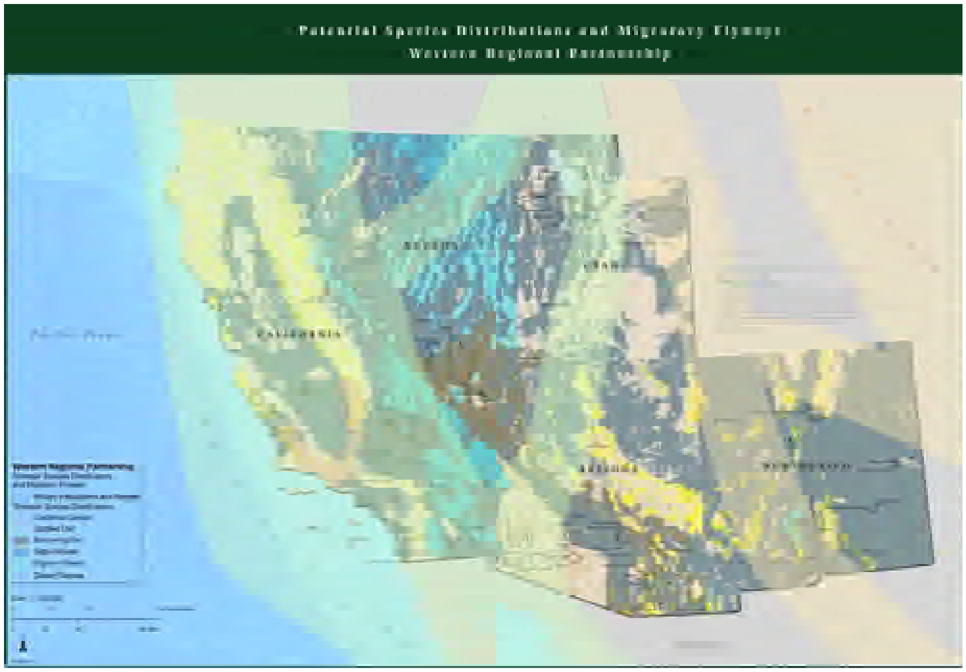

Figure 17. Stylized avian species migratory distributions and pathways in some western states.

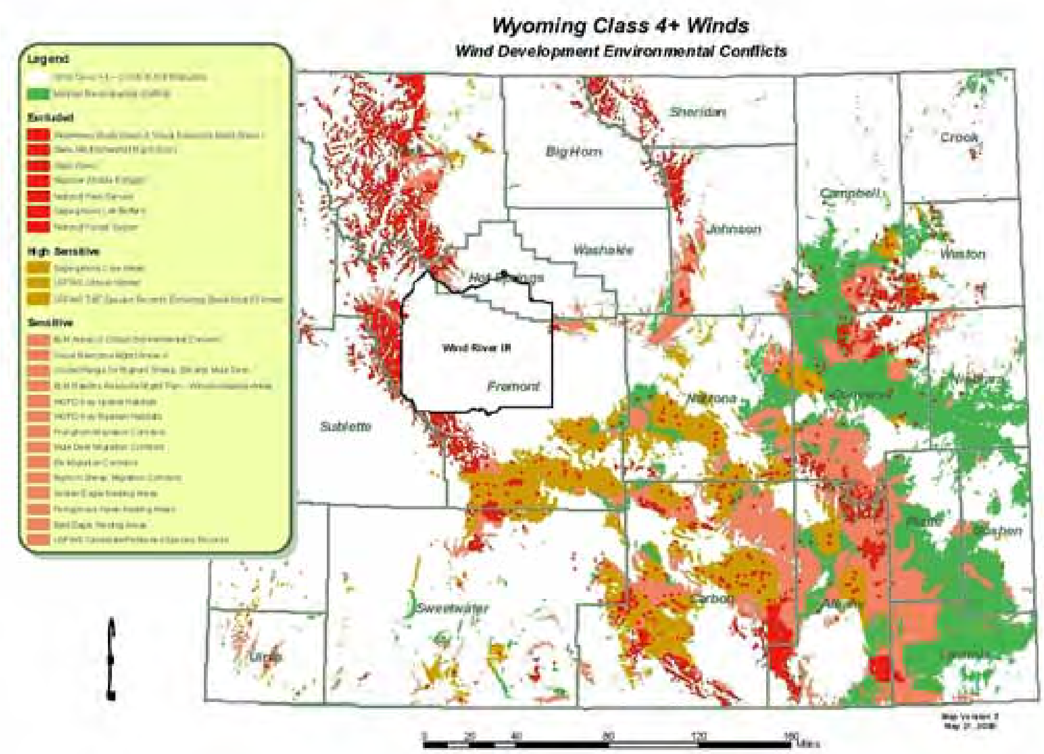

Figure 18. Example of renewable wind energy environmental developmental conflicts.

Water resources

While most interest in renewable energy developments has focused on terrestrial sites, those associated or using water resources also require significant ecologic consideration. From an ecological standpoint, alterations in water temperature, quality, volume or seasonally available flow, and other factors are important to all aquatic species, perhaps especially (in the case of marine or offshore projects) to marine mammals.

The importance of water resources in ecological and biological considerations is obvious. However, the impacts of renewable energy projects on ground and surface water sources, use, allocation, distribution, quality, and disposal is also of high concern. Many of the areas of the country with great potential for renewable energy development are also areas with limited water resources, where the growing human population is increasing water demand. Also, while the future cannot be predicted with certainty, it is likely that any global-warming-induced climate change will result in increased mean (or other) annual temperatures in these regions, and a consequently increased water demand.

Some renewable energy options require little, in any water. In fact, some generate water in the process of capturing and converting energy. However, the water requirements should be considered for each renewable energy development, whether the associated technology directly relies on water resources (e.g., biomass or geothermal energy), uses water as part of the energy generating process (e.g., bio-energy), or produces water as a product or byproduct (e.g., solar powered desalinization).

Air quality

At least indirectly, the effects of "greenhouse gases" with their cascading climactic influences, and the reduced air quality associated with them, are a strong impetus for reducing the use of (and dependency on) fossil fuels. As a group, emissions known as "greenhouses gases" include carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), nitrous oxide (N_2O), terafluromethane (CF4), hexafluoroethane (C_2F6), sulphur hexafluoride (SF_6), and hydrofluorocarbons ("HFCs").

An important advantage of renewable energy sources and the technologies that convert those energies into more usable forms is that renewable en-

ergy generally emits fewer compounds of concern (and in smaller quantities). However, some renewable energy sources and processes can produce significant quantities of GHGs. For example, the use of gases (primarily methane) derived from composting and landfill offer efficient and effective energy sources. However, such systems should be designed to control methane release to the atmosphere. Furthermore, any renewable energy process that uses combustion as a component will produce CO_2 and CO, along with other compounds and products (e.g., particulates). Likewise the use of HFCs has increased in the last decade or so as an alternative to ozone damaging CFCs (chlorofluorocarbons) in refrigeration systems. Unfortunately, though they provide an effective alternative to CFCs, they can also be powerful GHGs with long atmospheric lifetimes. Renewable energy systems that use HFCs as cooling components may become more problematic in the future.

Air space

Although the supply of air space is seemingly unlimited, like all other environmental resources, it is also finite (Figure 19). Large-scale development of renewable energy sources and infrastructure may create air space issues, most importantly when wind energy infrastructure is sited near military installations or military operating areas (training flight areas/routes used by the military). Large vertical structures such as windmills can cause physical flight route problems for military aircraft, and problems with the operation of military radar. Appropriate planning for siting renewable energy infrastructure can forestall air space conflicts. There must be widespread coordination and planning, not only within DOD, but also between private, local, state, and Federal groups and agencies.

Communications—including radar and sonar

The development of renewable energy sources and distribution networks as a category can be considered to have a neutral effect on communications technologies. However, as with most things related to the environment, there are exceptions. For example, wind turbines are known to interfere with radar and radio communication through obstruction, diffraction, reflection of electromagnetic signals, and Doppler clutter.

Figure 19. Delineated aircraft air space in some western states.

Wind turbines may also cause potential problems if located near such areas as: cell phone towers, microwave repeater stations, military communications installations, wireless Internet sites, radio repeater stations, remote telemetry monitoring stations, remote telecommunications sites, TV and radio broadcast towers, and (in offshore applications) marine sonar.

The overall effects of large scale development and placement of wind turbines near military radar systems is relatively unknown. Much of the equipment and technology in use has not been tested under large scale development. However, a large windfarm located near the western border of Edwards AFB at Tehachapi Pass in Southern California 20 years ago negatively affected the advanced military radar at the base. It took the Air Force several years to adjust to the situation and overcome the disruptive effects of the wind turbines.

Given present conditions, the current consensus is that, if they exist, these issues are manageable. However, the overall effects of large scale development and placement of wind turbines will remain unknown until much of the equipment and technology in use has been tested under large scale development conditions.

Noise

All industrial processes generate noise; the generation and use of renewable energy is no exception. At a National level, The Noise Pollution and Abatement Act of 1972 (42 USC 4901-42) establishes the Federal intent to protect human health and to enact requirements for local municipalities and counties to consider noise in their plans. Thus, from a broad environmental standpoint, noise from renewable energy development and resultant distribution, must be considered and addressed.

Although noise from renewable energy development can be characterized as minimal, total potential effects are at best uncertain. For example, the effects on wildlife of low level of noise such as that caused by wind turbines are unknown, but nonetheless potentially significant. In some locations, the low level "hum" of wind turbines has been identified as a disturbance by nearly communities. When sited near residential areas, such as those on military installations, turbine noise may be objectionable. In Michigan, this type of situation has resulted in county and other ordinances with complex and stringent noise requirements (e.g., see www.windaction.org).

Visual

The visual effects of renewable energy development should not be overlooked. For example, the sight of multiple wind turbines dotting the formerly open landscape and vistas may not be acceptable in all areas. A situation in Massachusetts illustrates this point. Although offshore wind turbine development in Nantucket Sound is apparently proceeding, it has not been popular with all segments of the public, and has resulted in an environmental review process that has extended over 7 years (The Boston Globe 2009). Large solar arrays, constructed on previously undisturbed or relatively natural landscapes, may also be visually undesirable to some.

Land use and land ownership

Some renewable energy sources require large areas for energy collection and/or generation. For example, solar panel arrays can require up to 10 acres per megawatt of power generated. In addition, lands will also be required to transmit, transform, store, and distribute this energy.

Much of the renewable energy development and deployment in the United States will be done with significant non-government involvement. In many instances, this development will take place on private lands (GAO 2005) (Figure 20). In these instances, it may be possible and feasible to implement renewable energy easements to facilitate the use of generated energy. If located on private lands, this will require provisions for energy transmission and distribution to military installation and other use centers. Current and future land use can play a significant role in the value of land used for renewable energy purposes. Renewable energy facilities in high value urban areas may not be economically feasible or environmentally practical.

Renewable energy development can also take place on Federal lands. In many areas of the United States, the Federal government is a significant if not the largest landowner (Figures 21 and 22). However differing Federal agency authorities, missions, and responsibilities can translate into differing environmental and ecological priorities and concerns. It will require concerted interagency coordination to reach agreement on how to effect renewable energy development (Figure 23). Toward that end, existing authorities allow for and direct DOD and other Federal agencies to integrate ecological and environmental planning and decisionmaking efforts (see Executive Order 13352 – *Facilitation of Cooperative Conservation*).

Figure 20. Private land renewable energy development.

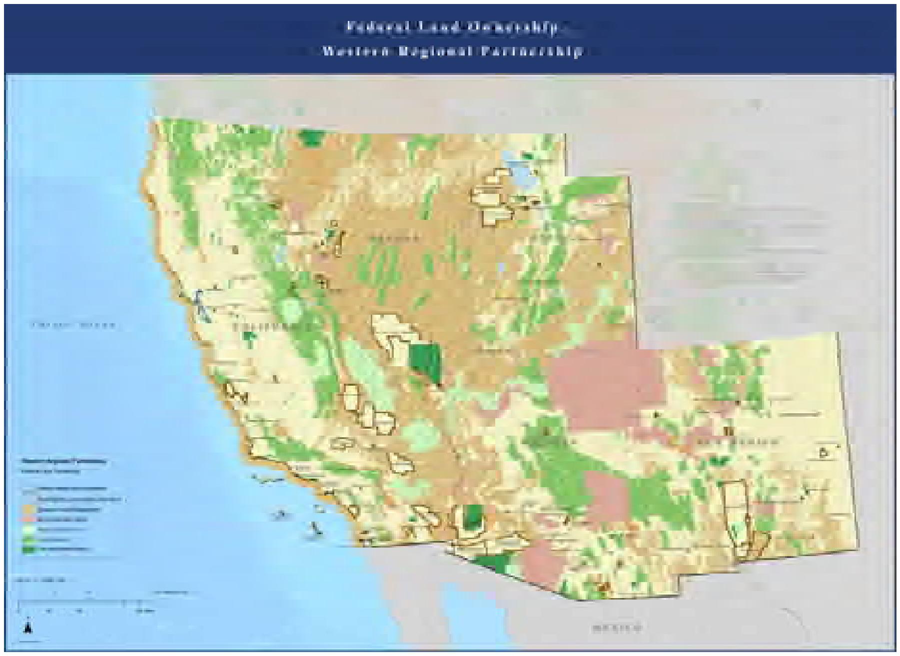

Figure 21. Land ownership in some western states.

Figure 22. Land ownership in southern California.

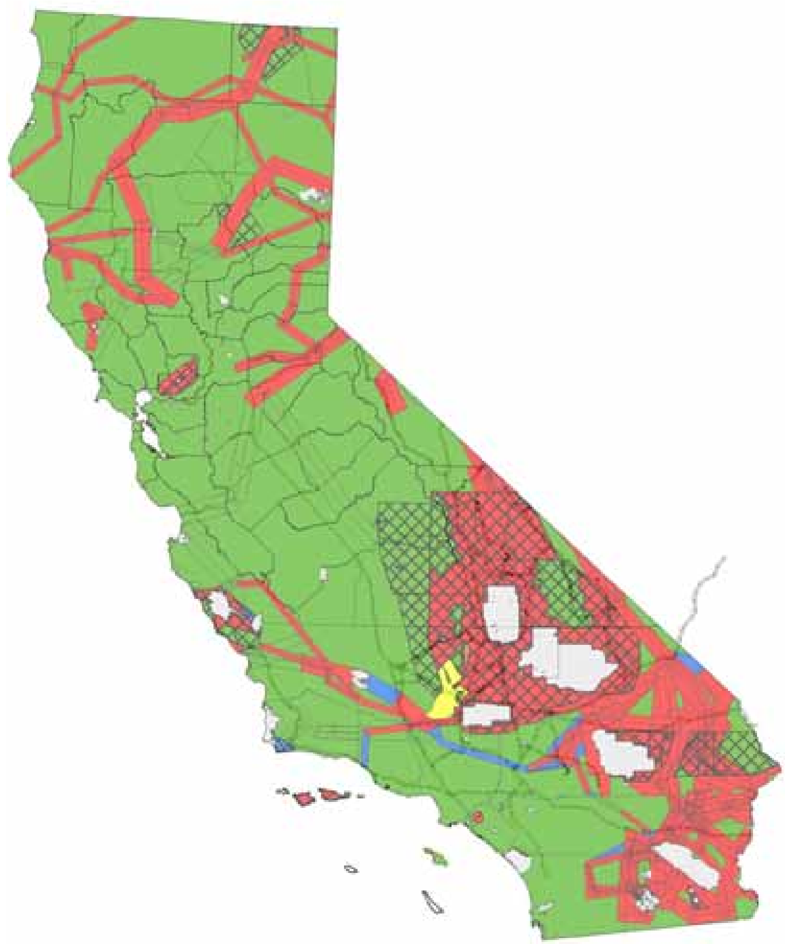

Figure 23. Example of red, yellow, and green constraint map for California.

Cultural resources

Cultural and historic resources are part of who and what we are as a nation. Numerous laws and regulations constrain Federal agencies from any action that unnecessarily disrupts culturally important resources. Federal laws such as the Native American Graves Protection and Repatriation Act (25 USC 3001 et seq.), require Federal agencies to consult with Native American groups on actions or items of interest. Other legislation calls for assessments of cultural resources on sites of proposed actions. Renewable energy developments should strive to avoid any negative impact on cultural resources. This is perhaps most appropriate and relevant when dealing with Native American entities (e.g., Tribes as Trustees of various environmental resources).

Urban growth

Growth of urban and suburban population centers has been in progress for decades and is in fact accelerating. The military, and the Army in particular, originally established installations in rural areas away from population centers. As the U.S. population has grown, and as installations have become important job sources for local populations, urban sprawl now abuts many installations (Figure 24). Noise, dust, and smoke from weapons, vehicles, and aircraft from training and other military operation can conflict with adjacent civilian use. In this context, renewable energy development also has the potential to become a conflict.

Since 2004, the military services have had the ability (as part of overall DOD Sustainable Ranges Initiatives) through the Readiness and Environmental Protection Initiative (REPI) to address issues of potential encroachment on military training. This effort emphasizes the need for installations to look "outside the fence" and to work constructively and creatively with communities and other stakeholders to resolve issues and conflicts. In the words of Alex Beehler, Assistant Deputy Under Secretary of Defense in Environment, Safety, and Occupational Health, "DOD's REPI Program is about working with states, communities, and conservationists in a positive way to promote win/win land use approaches and solutions."

Each service has its own implementation of this program. The Army Compatible Use Buffer program (10 USC 2684a) allows an installation to work with partners to encumber land to protect habitat and training without acquiring any new land for Army ownership. This (or similar) programs could be implemented to promote renewable energy development while minimizing negative ecological and environmental effects.

Socioeconomic factors

The most obvious socioeconomic factor influenced by renewable energy development is related to jobs creation during planning, construction, operation and, eventually, disposal of these facilities. The energy industry has frequently been the source of significant movements of people to energy-related employments. The large influx of people to work in non-renewable energy production in areas such as Alaska and Wyoming has been well recognized.

Figure 24. Patterns of urban growth in some western states.

This migration results in demand and need for other social facilities (e.g., housing) and services (e.g., fire protection), and environmental amenities (e.g., recreation). While the number of jobs associated with renewable energy projects in any single location may be limited, there will be higher employment numbers during the construction phase, and the number of jobs per megawatt produced may compare favorably to other energy sources. These socio-economic factors are an important part of the total “system” consequences of renewable energy projects.

As already mentioned, a comprehensive renewable energy program or approach will have a private industry component. Certainly the private sector will be involved in the design and construction of renewable energy and related facilities. However, depending on the circumstance, private interests will also be involved in other (perhaps not so obvious) ways. For example, biomass (typically from agricultural crops) conversion to biofuels (agrofuels) can require major and significant conversions of cropland.

There are two common strategies of producing liquid and gaseous agrofuels. One is to grow crops high in sugar (e.g., sugar cane), starch (e.g., corn), or cellulose (e.g., grass) and the use fermentation processes to produce ethyl alcohol, otherwise referred to as ethanol. The second is to

grow plants that contain high amounts of vegetable oil such as the soybean. These oils are then heated to alter their viscosity so they can be burned directly in a diesel engine, or they can be chemically processed to produce fuels such as “biodiesel.” In recent years, such cropland conversion has taken place, supported by government programs to simulate agrofuel production. A consequence of this has been a reported increase in food prices (IMF Research 2007) and conversion of marginal land or land formerly in conservation programs into crop production (Ogle 2007). The overall merits of these conversions from an energy production or GHG footprint perspective is uncertain at best.

Transportation and utilities

Although technologies are developing that will increase renewable energy production efficiency, with some exception, there are probably few military installations capable of supporting large utility-sized renewable energy systems (Report to Congress 2005). Thus, acquiring (i.e., purchasing) transported renewable energy may be a practical option.

While the technology of energy transportation is established, it is not necessarily easy—and may be (both financially and environmentally) costly. While electrical energy from wind and solar renewable energy sources can be said to move easily, it nonetheless requires an infrastructure distribution system that may or may not adequately exist. On the other hand, renewable energy in the form of heat from solar and geothermal sources is not easily transported.

In any event, the transportation of renewable energy can have ecologic effects—resulting from new construction of distribution systems (and associated roads), other infrastructure, and human activity. Such effects might include habitat fragmentation, life form behavioral disruption, facilitated invasion of exotic species, introduction of hazardous materials, etc. The extent of transportation systems needed to develop and sustain renewable energy resources, and their resulting ecological impact may even potentially be greater than that associated with continuing nonrenewable energy development (Figures 25–27).

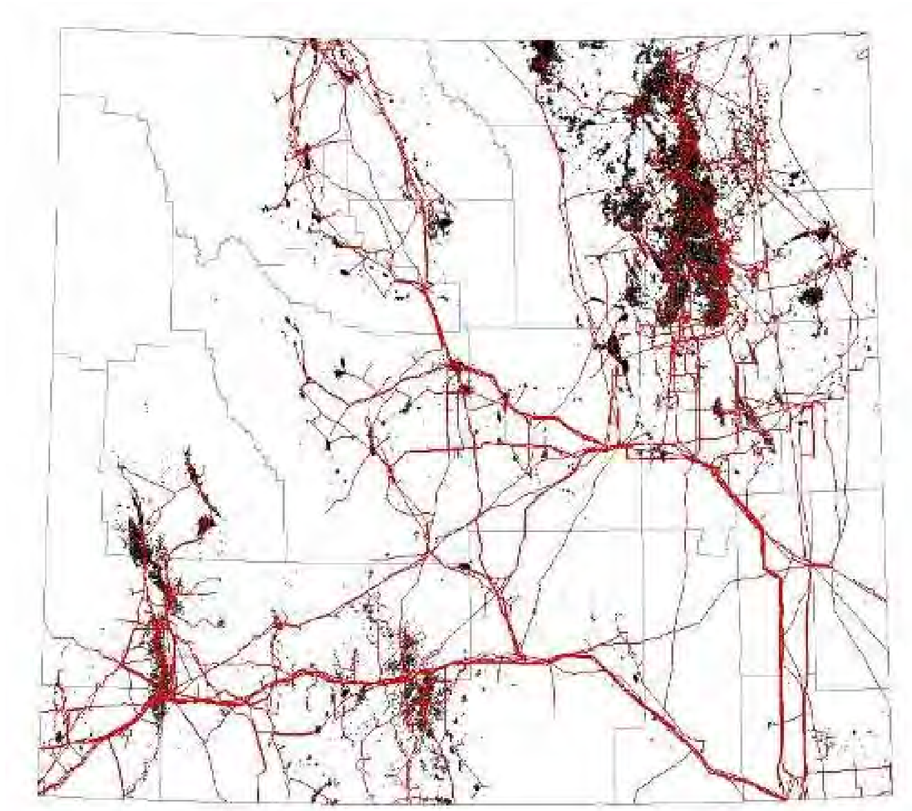

Figure 25. Oil and gas pipeline and well systems in Wyoming.

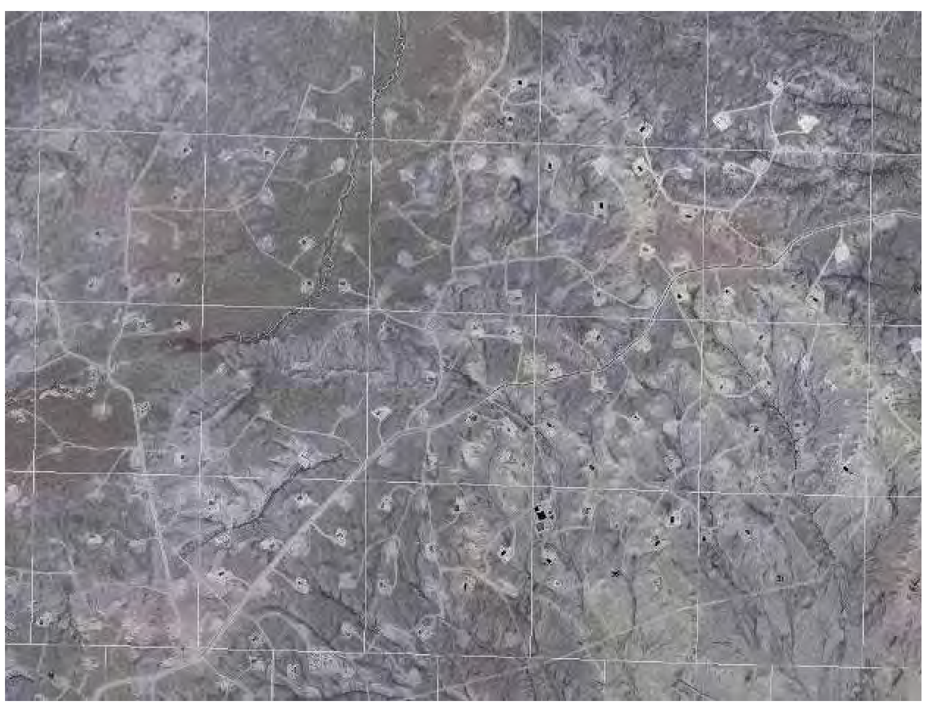

Figure 26. Aerial view of the Jonah Field, WY showing local service roads and other infrastructure.

Figure 27. Energy transportation lines, routes, and corridors in some western states.

Environmental justice

Executive Order 12898 (*Federal Actions To Address Environmental Justice in Minority Populations and Low-Income Populations*) requires that Federal agencies, within the context of their operations, address environmental (and other) condition of minority and low-income groups. The development of renewable energy resources in some regions of the country, particularly if approximated with international borders, may affect these (and other) populations. Any renewable energy development scenario should consider this and other environmental analysis requirements.

Waste management and hazardous materials

By its nature, renewable energy is generally clean and results in little direct pollution. Geothermal energy may an exception to this in that hazardous gases and minerals, and water or steam may come from underground when geothermal energy is harvested. One of the most common substances to be released is hydrogen sulfide, which is extremely difficult to dispose of safely. Other minerals that can be troublesome are arsenic, mercury, and ammonia. In addition to the possibility that geothermal energy extraction may release hazardous gases and minerals, there is the possibility that it may also cause earthquakes.

Another “less clean” renewable energy source is the use of animal waste to generate methane. Disposal of the waste and associated odors from this process may be problematic.

A number of hazardous materials are used in the manufacturing process of PV power modules, but the practice is closely regulated and manageably confined to the production site. However, one PV technology, the Cadmium-Telluride (CaTe) solar cell, uses a hazardous material (cadmium) for the solar cell itself. If a CaTe power module were damaged in the field, the fragments would have to be dealt with as hazardous waste.

Recreation

Renewable energy and land and water-based recreation in and of themselves can be considered compatible. However, they may be considered as conflicting land uses on some public lands and segments of the public. For example, recreational use of Federal (but non-DOD) lands converted to solar or other renewable energy productions might be curtailed. An example of this concern can be found with Department of Interior Bureau of Land Management lands associated the National Training Center in California. These situations will require careful planning and coordination among Federal and state agencies and public interest groups. On military installations, renewable energy production sites may have to be considered as restricted entry areas. As well as increasing infrastructure construction, maintenance, and administrative costs (e.g., fencing, patrol), this may result in reduction of land area available to outdoor recreational use by installation residents and others.

Cumulative effects

The cumulative effects of renewable energy developments cannot be overlooked. For example, reports of large numbers of birds and bats being killed at wind turbine developments raise concerns about cumulative population-level impacts of that technology. The impacts of multiple wind energy developments along a migratory bird flight path are as yet unknown. Siting considerations may need to be assessed at multiple scales to fully understand the “system” impacts of multiple renewable energy projects. Similarly, the siting and development of renewable energy sources and facilities can also result in changes in human demographics brought

about by the new availability of energy in differing locations and the resultant demands on other ecosystem attributes such as water.

Unfortunately, cumulative effects are difficult to measure and even more difficult to predict. Additionally, there can be differing criteria as to determining what cumulative effects and impacts may exist and may be important. The National Environmental Policy Act (NEPA), for example, defines "cumulative effects" as the impact on the environment that results from the incremental impact of the action when added to *all* other past, present, and reasonably foreseeable actions (40 CFR 1508.2). With regard to listed species, the Endangered Species Act defines cumulative effects as those effects of future State or private actions that are reasonable certain to occur (50 CFR 402.2). At the very least, the identification of cumulative environmental effects is mandated in any environmental review and planning for renewable energy projects (Figure 28).

Regulatory considerations / authority

A significant amount (if not most) of renewable energy development takes place on private lands (GAO 2005). The Federal government plays a minimal role in approving renewable energy power facilities,* and is only involved in regulating facilities that are on Federal lands or waters, or that have some other form of Federal involvement such as where Federal funding is provided, where a Federal permit is involved, or where there is connection to a Federal power grid, e.g., the Western Area Power Administration or Bonneville Power Authority.

In that case, the renewable energy project must comply with Federal laws, such as NEPA. However, there can be overlapping or multiple jurisdictional considerations, as well as differing permitting processes and data requirements. For example, wildlife conservation in the United States (with the exception of Federal trust species [e.g., threatened or endangered species]) lies within the exclusive jurisdictional authority of the States. Also, most States have statutes that can be applied to regulate siting, construction, and operation of renewable energy producing facilities.

* Notable exceptions are those involving nuclear or hydroelectric generation, which are outside the scope of this report. The regulatory nexus is not with renewable energy generation per se, but rather is with Nuclear Regulatory Commission, Clean Water Act, and other, primarily environmental, regulations.

Before After

Figure 28. Cumulative effects of wind energy development are easy to observe, but difficult to quantify.

Ecosystem and environmental considerations for renewable energy developments must include local zoning. Zoning regulations vary from state to state and from one local jurisdiction to the next (Figure 29). While existing zoning laws seldom categorically address renewable energy generation, they may still apply (Table 2). In some specific situations, Tribal regulations may also apply. Table 3 lists a summary categorization of ecosystem and environmental considerations for renewable energy developments.

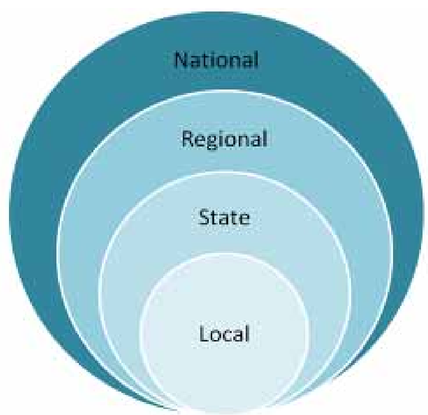

Figure 29. Structure of regulatory authority.

Table 2. Summary of state delegation of zoning authority.

Qualification	Number
States with zoning enabling laws	50
States with state-level zoning authority	2
States with county zoning authority	39
States with town/township zoning authority	13
States with municipal zoning authority	49
Estimated number of local zoning jurisdictions	20,000

Table 3. Large-scale renewable energy technology vs. ecosystem considerations.

	Geology, Soils, Seismic Activity	Climate	Biology	Water Resources	Air Quality	Air Space	Communications	Noise	Visual	Land Use and Land Ownership	Cultural Resources	Urban Growth	Socioeconomic Factors	Transportation and Utilities	Environmental Justice	Waste Management and Hazardous Materials	Recreation	Cumulative Effects	Regulatory Considerations/Authority
Solar – PV*		X	X		X				X	X	X	X	X	X	X	X	X	X	X
Solar – Concentrating PV		X	X	X	X				X	X	X	X	X	X	X	X	X	X	X
Solar – Concentrating Thermal Electric*		X	X	X	X				X	X	X	X	X	X	X	X	X	X	X
Wind	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X
Biomass (Energy Crops and Biofuels)	X	X	X	X						X	X	X	X	X	X	X	X	X	X
Biomass (Waste-to-Energy)			X	X						X	X	X	X	X	X	X	X	X	X
Geothermal	X			X	X				X	X	X	X	X	X	X	X	X	X	X

* There are three major concentrating solar thermal electric technologies that might be considered: (1) parabolic trough (upper left photo), (2) concentrating dish sterling, and (3) power tower.

5 Conclusions and Recommendations

Conclusions

A very aggressive approach will be needed to increase the number of renewable energy projects being developed on or near DOD lands. The need to meet Federal government and DOD energy security and greenhouse gas reduction goals will require the initiation of more (and many large-scale) renewable energy projects.

A first step in this effort is to investigate constraints (planning, logistical, legal, contracting and finance, environmental, water resources, etc.) involved in establishing successful renewable energy projects. The support resulting from these investigations must be varied and accessible, e.g., quick response teams of experts, knowledge-based web tools, and evolving guidance, which together will enable DOD organizations to face and meet these challenges. Such support will help decisionmakers anticipate and mitigate constraints so renewable energy projects do not suffer delays, or yield unforeseen consequences.

Appropriate investments in assistance and expertise will pay great returns, given the high cost (and risk of failure) of poorly planned projects. To that end, the Army and other DOD agencies should:

- increase the knowledge base to execute renewable energy projects (both electrical and thermal)
- develop a cadre of technical, legal, and contracting personnel to facilitate more projects and/or alternatively financed projects
- clarify to the Congress, the President, and states where the current laws do not facilitate the accomplishment of large scale renewable energy projects.

As Pulitzer Prize Winner Thomas Friedman asserts, leadership provided by DOD and the military services will significantly guide the nation in its efforts to achieve and maintain energy security:

> Pay attention: When the U.S. Army desegregated, the country really desegregated; when the Army goes green, the country could really go green."
> *Thomas Friedman, Pulitzer Prize Winner and Author of Hot, Flat and Crowded: Why We Need a Green Revolution and How It Can Renew America.*

Recommendations

Technical support services

Coordinating the many planning, environmental, and logistical considerations associated with renewable energy projects represents a significant challenge; energy managers and planners at all levels of the organization struggle to address all the technical, logistical, land management, and other challenges. It is recommended that a multi-venue analytical cell and technology support service be provided within the DOD to effectively provide enterprise guidance, tradeoff research results, user-generated information, and renewable energy guidelines. This service should provide technical, legal, real estate, and contracting capabilities. Such a service might be most cost effective at the DOD level, rather than for each individual military service. This service may also help analyze best “opportunities” to effectively and efficiently exploit renewable resources, as this analysis also involves complex factors.

Extensive coordination

Renewable energy projects are usually developed by energy managers, and need full coordination with the mission operators on the impacted base(s), as well as the environmental planners, and real estate, legal, and contracting agents. It is recommended that an analysis of sites proposed for renewable energy projects consider their potential impacts on current and future mission activities. Coordination should include both opportunities (such as local energy use partnering) and constraints (such as potential mission concerns from solar panel reflectance or wind towers and radar), and should occur at both local and military service levels.

Evaluation of authorities, partnering and finance mechanisms

The DOD commonly accommodates renewable energy projects through 3rd party investments and agreements to provide access to land and facilities. Some of these authorities need to be better tailored to the complexities associated with renewable technologies. It is recommended that an analysis be done to determine the most appropriate authorities for development of renewal resources on military bases and in support of military base energy requirements, considering authorities and constraints at each jurisdictional level. Funding mechanisms and revenue distribution should also be considered in this analysis. The Sikes Act, which provides authority for forestry, grazing, and other activities on military bases, is a relevant

model to consider in this analysis, including the manner in which the Act provides for the distribution of resources.

Guidelines for planning

Renewable energy plans for the DOD and for other relevant public organizations need to be informed by an improved understanding of the planning considerations associated with project (especially those, on unimproved land), and guidelines should be developed to help focus project proposals in a way that minimizes undesirable consequences. It is recommended that the DOD develop a set of guidelines that are sensitive to mission, environmental, human health, energy infrastructure management, and other potential concerns. These guidelines will change over time as more is learned about the unanticipated impacts of renewable energy projects, so it will be useful to make guidelines available in a framework that allows for frequent updates. These guidelines should continuously reduce the complexity and time required for renewable project planning.

Accommodating technology evolution and market fluctuations

Renewable technologies have improved during the last decades; even greater future investments in these technologies are likely. These continued investments may result in more efficient wind turbine designs, more efficient solar panels (or entirely new methods to concentrate or store energy from these technologies), increased application of bio-fuel technology, and wider availability of geothermal energy. It is important to plan for these technology changes, and to determine whether legacy renewable infrastructure will be upgraded or bypassed. As with other types of infrastructure development, it may be more cost effective for renewable energy developers to convert new undeveloped land for new renewable technologies than to retrofit legacy renewable infrastructure. It is recommended that technology evolution issues be considered in the partnering and financial arrangements that Defense organizations make for renewable resources — to prevent future “renewable junkyards” and “renewable brownfields” across DOD bases as technologies become outdated, or market fluctuations cause some developers to abandon projects.

Lesson learned

It is recommended that DOD organizations develop protocols for data collection from all renewable energy projects to include partnership mechanisms, local constraints and tradeoff considerations, operational charac-

teristics, arrangements for energy sharing, production results, and any problems that may occur on the sites. This information should become part of a repository of renewable energy information sources to provide valuable references for those making new arrangements, for those conducting outcome evaluations, and for those researching new and improved approaches for renewable energy operations.

Tradeoff research

It is recommended that research be initiated to better inform decision-makers of the tradeoffs between renewable energy projects and the ecological, mission, and other unintended consequences of these projects. These tradeoffs are not well understood and should consider ecosystem services, GHG, energy production, and other criteria as tradeoff measures. These are also needed for multiple types of renewable energy options — bio-energy, solar, wind, geothermal, hydro, etc. In addition, long-term studies are needed to address many questions on impacts of renewable energy development or acquisition on ecosystem components, human health and mission capability. Some of the impacts may not be apparent in short term studies, and the types of impacts may differ over time as land use intensifies in regions where renewable infrastructure is sited, or where biomass is generated for biofuels. These studies are needed to inform and improve the plans and operations for long-term renewable energy projects, to help shape new projects, and to better understand and anticipate the cumulative impacts of multiple projects. Issues such as long-term ecosystem impacts, carbon balance from bio-resources, technology evolution, infrastructure degradation, etc. need to be addressed to minimize any negative effects resulting from renewable energy efforts.

Acronyms and Abbreviations

Term	Spellout
ADG	Anaerobic Digester Gas
ACSIM	Assistant Chief of Staff for Installation Management
AEPI	Army Environmental Policy Institute
AFB	Air Force Base
ANSI	American National Standards Institute
ARS	Agricultural Research Service
CASI	Center for the Advancement of Sustainability Innovations
CaTe	Cadmium-Telluride
CERL	Construction Engineering Research Laboratory
CFR	Code of the Federal Regulations
CO	carbon monoxide
CONUS	Continental United States
DOD	U.S. Department of Defense
ECIP	Energy Conservation Investment Program
ERDC	Engineer Research and Development Center
ERDC-CERL	Engineer Research and Development Center, Construction Engineering Research Laboratory
ESPC	Energy Savings Performance Contract
EUL	enhanced use lease
FY	fiscal year
GAO	Government Accountability Office
GHG	Greenhouse Gas
HRI	heat recovery incinerator
IMF	International Monetary Fund
MSW	Municipal Solid Waste
MW	megawatt
NAWS	Naval Air Weapons Station
NEPA	National Environmental Policy Act
NOL	notice for opportunity to lease
NSN	National Supply Number
OECD	Organization for Economic Co-operation and Development
OMB	Office of Management and Budget
PPA	Power Purchase Agreement
PPV	Public Private Venture
PV	photovoltaic
REC	Renewable Energy Certificate
REPI	Readiness and Environmental Protection Initiative
SEFI	UNEP Sustainable Energy Finance Initiative

Term	Spellout
SEGS	solar electric generating system
SR	Special Report
TREC	Tri-Service Renewable Energy Committee
UN	United Nations
UNDP	UN Development Programme
UNEP	UN Environment Program
UESC	Utility Energy Services Contract
USC	United States Code
USDA	U.S. Department of Agriculture

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Key Regulatory and Policy Drivers

Army Environmental Policy

Army Regulation 200-1 Environmental Protection and Enhancement

Army Regulation 200-2 Environmental Effects of Army Actions

Army Regulation 200-3 Natural Resources

Army Regulation 350-19 Sustainable Range Program.

Clean Air Act

Clean Water Act

DOD Environmental Policy

Endangered Species Act

Energy Independence and Security Act

Energy Policy Act

Executive Order 13123 - Greening the Government Through Efficient Energy Management (Revoked by EO 13423)

Executive Order 13423 - Strengthening Federal Environmental, Energy, and Transportation Management

Executive Order 13514 – Federal Leadership in Environmental, Energy and Economic Performance Marine Mammals Protection Act

Migratory Bird Treaty Act

National Environmental Policy Act

National Historic Preservation Act

Noise Control Act

Relevant Air Force Policy and Regulations

Relevant Marine Corps Policy and Regulations

Relevant Navy Policy and Regulations

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14. ABSTRACT
The U.S. Federal government is pursuing a policy to reduce the rate of fossil fuel consumption, to provide more energy from local, renewable sources, and to effectively use Federal resources to help achieve these goals. Actions supporting these goals are now putting significant pressures on U.S. military bases to provide physical space for wind generators, for solar panel arrays, for bio-energy production, for the transformation of energy from one form into another, and for the entire associated infrastructure related to the operation, transmission, and service of these energy assets. This document explores as-yet unanswered questions related to the potential impacts of these new renewable energy infrastructures on the military installations. Installation Managers need to make informed decisions about the tradeoffs between renewable energy production and ecosystem services, between energy and water availability, and between energy production and current or potential future mission use. This study was undertaken to help inform those decisions.

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